Research Statement

A. Research Interests

My research interests are focused on the intersection of applied mathematics, optimization, machine learning, manufacturing engineering, and supply chain management. I have a strong background in preparing and submitting research proposals to various funding bodies, including the Swiss National Science Foundation (SNSF), Innosuisse, Leading House, and other international organizations. This experience is enhanced by my ability to collaborate effectively with international teams, enabling me to develop and present research projects that align with the rigorous standards of funding agencies.

I have been involved in a range of research projects, including:

B. Projects Summaries

1. Leveraging Digital Technologies for Enhancing Dairy Supply Chain Resilience and Viability: Addressing Challenges in Waste Management, Transparency, and Traceability in Switzerland

This research investigates the drivers and barriers to adopting Digital Technologies (DT) in Dairy Supply Chains (DSCs), focusing on their potential to enhance resilience and long-term viability. Specifically, it evaluates DT's impact on SC resilience and develops strategies to mitigate vulnerabilities. The project focuses on advanced disruption detection and resilience for the Gruyère AOP Supply Chain (GASC), an emblematic Swiss product made exclusively with Swiss-origin ingredients. By optimizing waste management, transparency, and traceability, GASC serves as a model for enhancing sustainability and resilience in Swiss supply chains.

This project seeks to explore DT adoption, its impact on SC sustainability, and develop disturbance detection systems and resilience strategies Dairy SCs (DSCs), with a specific focus on the GASC. By optimizing waste management, transparency, and traceability, the project aims to enhance resilience and support the long-term sustainability and viability of GASC.

The methodology combines multi-criteria decision-making (MCDM) and structural equation modeling (SEM) to analyze data collected from the agri-food industry in both countries. SEM will identify interrelationships among factors and address the limitations of MCDM, ensuring comprehensive insights. This study contributes to advancing digital technologies in sustainable supply chain management, offering practical tools for designing distribution networks, enhancing traceability, and fostering responsiveness in agriculture supply chains.

The proposal is submitted to the Federal Office for Agriculture (FOAG).

2. Integrating Blockchain and Internet of Things for Healthcare Waste Management

This research explores the integration of blockchain (BLC) and Internet of Things (IoT) technologies to address healthcare waste management challenges, focusing on healthcare sector. With hospitals generating significant amounts of general and hazardous waste, effective management is critical to mitigating health risks, preventing disease transmission, and reducing environmental contamination.

Industry 4.0 technologies like IoT and blockchain offer transformative potential through real-time monitoring, secure data sharing, and enhanced traceability. The study investigates the central question: *What are the challenges in adopting BLC and IoT in healthcare sector for efficient waste management?* Key objectives include identifying critical barriers to the adoption of BLC-IoT for reverse logistics (RL) of recyclable hospital waste, analyzing contextual and causal relationships among these barriers.

The methodology involves gathering insights from healthcare experts, prioritizing challenges using the Best-Worst Method (BWM), and analyzing cause-and-effect relationships through Decision-Making Trial and Evaluation Laboratory (DEMATEL). Sensitivity analyses will validate the robustness of findings. By addressing barriers and offering actionable insights, the research aims to inform stakeholders, policymakers, and researchers in developing strategies for successful BLC-IoT integration. The research promotes the integration of circular economy (CE) principles into healthcare waste management, supporting sustainability objectives within healthcare ecosystems.

The proposal submitted to the Qatar National Research Fund (QNRF).

3. Agile and sustainable closed-loop supply chains in hydrogen powered mobility ecosystems

In the pursuit of reducing greenhouse gas emissions and advancing the global energy transition, clean and efficient alternative energy sources have become a critical focus. Hydrogen, recognized for its low emissions and high energy efficiency, is increasingly used in electric vehicles. However, its production remains costly and energy-intensive, and the collection and distribution of hydrogen cartridges pose significant logistical challenges.

This research, conducted in collaboration with the University of Applied Sciences Geneva and the company STOR-H, aims to design an optimized supply chain for hydrogen cartridges that minimizes infrastructure costs and CO2 emissions. The study focuses on determining the optimal number and locations of distribution centers and devising efficient distribution and collection routes for cartridges. The Capacitated Vehicle Routing Problem (CVRP) is employed to model these routes, aiming to minimize travel distances while adhering to vehicle capacity constraints. Four optimization techniques—Simulated Annealing (SA), Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Hybrid Particle Swarm Optimization (HPSO)—are applied to address these challenges. The research evaluates two models, managing three and ten vending machines (VMs), across three operational scenarios: Balanced, Pessimistic, and Optimistic.

The findings offer strategic recommendations to optimize costs and CO2 emissions in similar logistics setups. By implementing these insights, companies can enhance the cost efficiency and environmental sustainability of their hydrogen cartridge distribution operations.

The project was funded by Innosuisse, with a total budget of 282,844.80 CHF and a duration of 2 years.

4. Framework for Natural Disaster Management: A Healthcare Services Continuity Plan for the Country of Morocco

This research addresses the urgent need for effective disaster management strategies to mitigate the devastating impacts of natural disasters, which annually affect approximately 218 million people and result in significant loss of life and infrastructure damage. Recent disasters, such as Morocco's earthquake and Libya's floods, highlight the critical importance of robust disaster response frameworks.

Focusing on Morocco, the study aims to develop a Natural Disaster Management (NDM) framework that integrates a Healthcare Services Continuity Plan (HSCP) to ensure the uninterrupted delivery of critical healthcare services during disaster situations. Central to this framework is the design of Disaster Logistics Networks (DLN), which play a vital role in disaster response. The research incorporates both strategic and tactical levels of decision-making:

1. **Strategic Level**: This involves designing DLNs by identifying optimal locations for emergency facilities, such as hospitals and dispensaries, to minimize response times and maximize regional coverage.
2. **Tactical Level**: This focuses on enhancing crisis management at individual facilities through improved local decision-making, optimal planning, and scheduling during emergencies.

The proposed framework builds on existing disaster management models and literature, introducing innovative approaches tailored to Morocco's unique geographical and social context. By emphasizing mitigation, preparedness, and efficient resource allocation, the project aims to reduce the loss of lives, economic impacts, and environmental damage.

The research improves regional coordination, enhances decision-making efficiency, and provides a comprehensive decision-support system for disaster management in Morocco. This framework serves as a valuable tool for policymakers, emergency planners, and healthcare providers, fostering resilience and preparedness in the face of future natural disasters.

The proposal submitted to the Leading House for the Middle East and North Africa (LHMENA).

5. **Design of Humanitarian Relief Logistic Networks with Consideration of Pre- and Post-disaster Management**

The rising frequency and severity of disasters, driven by rapid population growth and increased human settlement in hazardous areas, have heightened the need for robust and efficient disaster management strategies. In humanitarian relief operations, human behavior during emergencies introduces significant uncertainties, which, if overlooked, can cause delays and inefficiencies in relief distribution. Enhancing the quality and responsiveness of disaster relief operations through the design of effective Disaster Logistic Networks (DLNs) has therefore become an urgent priority.

This research addresses the critical need to bridge the gap between theoretical frameworks and practical applications in the field of humanitarian logistics. It focuses on developing optimization models for pre- and post-disaster DLNs that integrate prevailing risk factors to address real-world challenges. By incorporating risk-averse strategies, these models aim to optimize service levels and response times while balancing the increasing demand for cost-efficient solutions. A novel decomposition model will be introduced to solve complex optimization problems using realistic data, ensuring practical applicability.

Existing literature highlights the limitations of current mathematical models and solution approaches in capturing the complexities of disaster logistics. This research introduces two key innovations: (1) comprehensive consideration of pre- and post-disaster factors, including casualty transportation to healthcare facilities, in the DLN design, and (2) the integration of risk measures into scenario-based models to assess the impact of disasters on the networks. These advancements will enable the identification of critical factors influencing system performance and provide optimal solutions for enhancing relief quality, response time, and cost efficiency.

The research contributes significantly to both academic and practical domains. It provides actionable insights for researchers and practitioners in humanitarian logistics, supporting evidence-based decision-making in the design and management of disaster logistics networks. Ultimately, this work aims to improve the effectiveness and responsiveness of relief operations, ensuring better outcomes for communities affected by crises.

The project was funded by LHMENA, with a total budget of 12,500 CHF, and had a duration of 1 year.

6. **Demand Forecasting and Inventory Management for Short Life Cycle Products Using Social Media Data and Expert Insights**

This research focuses on improving demand forecasting and inventory management for short life cycle products to maximize customer fulfillment, minimize obsolescence, and optimize stock levels. Accurate demand forecasts are crucial for making optimal ordering decisions. The study develops a novel methodological approach that integrates social network data and expert judgment to enhance forecasting accuracy and inventory management efficiency.

Social network data is categorized into three dimensions: (1) quantitative (e.g., past sales of similar products) and qualitative (e.g., expert insights), (2) structured, semi-structured, or unstructured (e.g., data from platforms like Twitter and Facebook), and (3) endogenous (internal data) or exogenous (external sources). Leveraging this data, the research adopts a three-stage approach:

1. **Hierarchical Demand Forecasting Procedure**: This stage combines structured and unstructured quantitative and qualitative social network data to refine demand forecasts. These insights are then enriched with expert judgment to improve forecasting accuracy.
2. **Probabilistic Inventory Management Model**: Inspired by the Newsvendor problem, this model utilizes the enhanced forecasts to optimize inventory levels, balancing the trade-offs between stockouts and excess inventory.
3. **Real-World Case Studies**: The proposed methodology will be tested and validated using real-world data from two companies. These companies will contribute data, validate diagnostics, support model development, and test the techniques and algorithms in operational environments.

The research provides actionable insights into demand forecasting and inventory management, offering practical tools for companies to optimize their operations. By integrating social network data and expert judgment, this approach improves decision-making accuracy and supply chain efficiency, particularly for products with short life cycles.

The proposal submitted to the Qatar National Research Fund (QNRF).

7. Design and Planning of Reverse Sustainable Supply Chains for Clinical Trials Under Uncertainty

This research focuses on developing a sustainable and reverse logistics framework for the clinical trial supply chain, addressing the environmental, economic, and societal challenges associated with waste management. The clinical trial ecosystem generates significant waste from unused medications, packaging materials, and single-use medical devices, necessitating innovative approaches to recycling and resource optimization without compromising operational efficiency or drug/vaccine efficacy.

The project introduces mathematical programming models to design and optimize reverse logistics networks within clinical trial supply chains, emphasizing circular practices such as reuse, recycling, and responsible disposal. These models account for the complexity of supply chain operations, uncertainties in demand and supply, and the collaborative interactions between stakeholders. To enhance practical application, the research investigates decomposition techniques to improve computational efficiency and enable realistic data integration.

Key objectives include achieving sustainability across economic, environmental, and social dimensions, improving resilience to unforeseen challenges, and aligning with eco-friendly practices. The study uniquely integrates stochastic demand considerations with reverse logistics and network design, addressing both tactical and strategic decision-making under uncertainty. This innovative approach enhances sustainability in clinical trials by connecting theoretical models with practical applications, enabling informed decision-making for sustainable waste management and reverse logistics while addressing the broader social and environmental demands of society.

The proposal submitted to the Swiss National Science Foundation (SNSF).

C. Future Research

Given my involvement in various research projects, I have several ideas to propose. However, these two research proposals particularly interest me:

Research Proposal 1

Designing a Large-Scale Dial-a-Ride System with Shared Autonomous Vehicles for Disaster Evacuation

Future research will focus on the development of large-scale Dial-a-Ride systems utilizing Shared Autonomous Vehicles (SAVs) to enhance evacuation logistics in disaster scenarios. Traditional emergency transport systems are constrained by the inflexibility of human-operated fleets. In contrast, SAVs offer dynamic deployment, real-time adaptability, and coordinated response capabilities that can significantly enhance emergency preparedness and post-disaster recovery.

This research will focus on developing novel models and scalable solution approaches for various forms of the Humanitarian Dial-a-Ride Problem (HDARP), incorporating heterogeneous SAV fleets. The project will address both **pre-disaster (deterministic)** and **post-disaster (stochastic)** scenarios, under dynamic, uncertain environments. Key problem extensions will include shared multi-depot configurations and integration with mixed-mode transportation involving both autonomous and conventional public vehicles.

Two complementary *learnheuristic* approaches will be investigated:

- **Pre-Disaster Scenario (Dynamic & Deterministic HDARP):** A learnheuristic combining a modified Particle Swarm Optimization (PSO) algorithm with Variable Neighborhood Search (VNS) will be employed to enable adaptive routing. The system will include a hierarchical assignment mechanism prioritizing vulnerable populations, dynamic request assignment through predictive fleet planning, and real-time integration with public transport nodes. Machine learning components, including demand forecasting and disaster-aware SAV pre-positioning, will be powered by historical data and weather monitoring. Multi-Agent Reinforcement Learning (MARL) will support real-time coordination and adaptive routing.
- **Post-Disaster Scenario (Dynamic & Stochastic HDARP)**: An Adaptive Predictive Large Neighborhood Search (APLNS) approach will be developed, incorporating removal and insertion operators guided by urgency and zone-based strategies. Decision-making will be enhanced through the use of Deep Q-Networks (DQN), which are well-suited for learning optimal policies in highly dynamic and uncertain environments.

Both approaches will be supported by Mixed-Integer Linear Programming (MILP) formulations that capture key operational constraints, including flexible depot assignments, parking capacity, and coordination across multiple transport modes. In the mixed-mode setting, SAVs will focus on transporting injured individuals to hospitals, while conventional vehicles will handle evacuations to safe zones.

By integrating optimization, machine learning, and autonomous systems, this research aims to contribute robust, real-time decision-support tools for disaster resilience in urban mobility systems.

References

Kassoul, K., Zufferey, N., Cheikhrouhou, N., & Brahim Belhaouari, S. (2022). Exponential Particle Swarm Optimization for Global Optimization. IEEE Access, 10, 78320-78344. IEEE Access. https://doi.org/10.1109/ACCESS.2022.3193396

Research Proposal 2

Exponential Particle Swarm Optimization (ExPSO) for large-scale optimization

Introduction

Particle Swarm Optimization (PSO) is a popular heuristic algorithm known for its high convergence speed and simplicity. However, it faces significant challenges, such as premature convergence, particularly when applied to large-scale optimization problems. To address these limitations, this research proposal aims to enhance the Exponential Particle Swarm Optimization (ExPSO) algorithm, originally proposed by by Kassoul, Zufferey, et al. (2022), by integrating reinforcement learning (RL) mechanisms. The proposed enhancements seek to adaptively adjust the convergence speed and improve the balance between exploration and exploitation, thereby enabling more effective solutions to large-scale optimization problems.

Objective

1. **Development of an Adaptive ExPSO Algorithm**
   - Incorporate reinforcement learning techniques to dynamically balance exploration and exploitation phases during the optimization process.
   - Ensure the algorithm is specifically designed to handle large-scale optimization problems by maintaining diversity within the swarm and preventing premature convergence.

2. **Evaluation and Benchmarking**
   - Conduct extensive testing on benchmark functions to compare the performance of the enhanced ExPSO algorithm with traditional PSO and other state-of-the-art optimization algorithms.
   - Analyze the scalability, robustness, and overall effectiveness of the proposed algorithm.

Methodology

1. **Adaptive Swarm Population Division**

   Divide the swarm into three equal subpopulations, each employing a distinct search strategy based on an exponential function. This division will help in maintaining diversity and preventing premature convergence by enabling significant leaps in the search space.

2. **Exponential Search Strategy**

Integrate an exponential function into the velocity equation, allowing particles to make large jumps initially and smaller jumps as the search progresses. This strategy ensures thorough exploration of the search space early on and focused exploitation in later stages.

3. **Dynamic Velocity Control**

   Implement a dynamic velocity control mechanism where the velocity range of each particle is adaptively adjusted. A linear decreasing cognitive parameter combined with a dynamic inertia weight strategy will facilitate large jumps at the beginning and smaller, precise movements as particles converge towards optimal solutions.

4. **Reinforcement Learning Mechanism**

   Utilize reinforcement learning to adaptively adjust the convergence speed of the algorithm based on problem characteristics. The algorithm will learn from its performance and dynamically update its parameters for improved efficiency and effectiveness.

Expected Contributions

1. **Enhanced Algorithm Performance**

   The enhanced ExPSO algorithm is expected to outperform traditional PSO in large-scale optimization problems by effectively balancing exploration and exploitation through adaptive search strategies and parameters.
2. **Scalability**

   The proposed algorithm will be scalable, capable of handling high-dimensional optimization problems, and applicable to a wide range of real-world scenarios.
3. **Robustness**

   The integration of reinforcement learning mechanisms will improve the algorithm's robustness, enabling it to adapt to various problem landscapes and avoid premature convergence.

Preliminary Results

Initial testing of the ExPSO algorithm on 13 benchmark functions (Table 1) has shown promising results. These preliminary findings are summarized in Table 2, indicating the algorithm's potential for effectively solving large-scale optimization problems.

Termination Criterion

The algorithm terminates when reaching $1 \cdot 10^6$ function evaluations (MaxFES) using 30 individuals, or when the error value is smaller than 10^{-8} (i.e., $\left|f(\overrightarrow{x_{best}}) - f(\overrightarrow{x^*})\right| \leq 10^{-8}$|, where $\overrightarrow{x_{best}}$ is the best solution obtained so far by the algorithm and $\overrightarrow{x^*}$ is the global optimal solution. 30 independent runs are conducted for each function and each algorithm. The algorithms are implemented in Matlab R2020a and the experiments are performed on a PC with a 1.9-GHz Core (TM) i5CPU processor with 8 GB of RAM.

Conclusion

This research proposal aims to develop an advanced ExPSO algorithm that leverages reinforcement learning to dynamically adjust its convergence speed for large-scale optimization problems. By incorporating novel search strategies and adaptive mechanisms, the proposed algorithm will enhance the effectiveness, scalability, and robustness of PSO, providing a powerful tool for tackling complex optimization challenges.

References

Kassoul, K., Zufferey, N., Cheikhrouhou, N., & Brahim Belhaouari, S. (2022). Exponential Particle Swarm Optimization for Global Optimization. IEEE Access, 10, 78320-78344. IEEE Access. https://doi.org/10.1109/ACCESS.2022.3193396

Large-scale optimization (D=1000)

Exponential Particle Swarm Optimization (ExPSO)

Table 1. Description of the 13 benchmark functions

	Search space	f_{min}	f_{min}	Name
Unimodal functions	$[-100,100]$	0	$f_1(x) = \sum_{i=1}^{n} x_i^2$	*Sphere Function*
	$[-10,10]$	0	$f_2(x) = \sum_{i=1}^{n}\lvert x_i\rvert + \prod_{i=1}^{n}\lvert x_i\rvert$	*Schwefel's Problem 2.22*
	$[-100,100]$	0	$f_3(x) = \sum_{i=1}^{n}\left(\sum_{j=1}^{i} x_j\right)^2$	*Schwefel's Problem 1.2*
	$[-100,100]$	0	$f_4(x) = max\lvert x_i\rvert, 0 \le i \le n$	*Schwefel's Problem 2.21*
	$[-30,30]$	0	$f_5(x) = \sum_{i=1}^{n}(100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2)$	*Rosenbrock Function*
	$[-100,100]$	0	$f_6(x) = \sum_{i=1}^{n}(\lfloor x_i + 0.5\rfloor)^2$	*Step Function*
	$[-1.28,1.28]$	0	$f_7(x) = \sum_{i=1}^{n} i x_i^4$	*Noise Function 'Quartic'*
Multimodal functions	$[-500,500]$	−4.1898e+05	$f_8(x) = 418.9829 \cdot n - \sum_{i=1}^{N} x_i sin\left(\sqrt{x_i}\right)$	*Schwefel's Function*
	$[-5.12,5.12]$	0	$f_9(x) = \sum_{i=1}^{n}(x_i^2 - 10cos(2\pi x_i) + 10)$	*Rastrigin's Function*
	$[-32,32]$	0	$f_{10}(x) = -20exp\left(-0.2\sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}\right) - exp\left(\frac{1}{N}\sum_{i=1}^{N} cos2\pi x_i\right) + 20 + e$	*Ackley's Function*
	$[-600,600]$	0	$f_{11}(x) = \frac{1}{4000}\sum_{i=1}^{n} x_i^2 - \prod_{i=1}^{n} cos\left(\frac{x_i}{\sqrt{i}}\right) + 1$	*Griewank's Function*
	$[-5.12,5.12]$	0	$f_{12}(x) = \frac{\pi}{n}\{10sin^2(\pi y_i) + \sum_{i=1}^{n-1}(y_i - 1)^2 [1 + 10sin^2(\pi y_{i+1})] + (y_n - 1)^2\} + \sum_{i=1}^{n} u(x_i, 10,100,4)$ where $y_i = 1 + \frac{1}{4}(x_i + 1)$, $u(x_i, a, k, m) = \begin{cases} k(x_i - a)^m, & x_i > a \\ 0, & -a \le x_i \le a \\ k(-x_i - a)^m, & x_i < a \end{cases}$	*Generalized Penalized Function 1*
	$[-50,50]$	0	$f_{13=}0.1\{sin^2(3\pi x_i) + \sum_{i=1}^{n}(x_i - 1)^2 [1 + sin^2(3\pi x_i + 1)] + (x_n - 1)^2[1 + sin^2(2\pi x_i)]\} + \sum_{i=1}^{n} u(x_i, 5,100,4)$	*Generalized Penalized Function 2*

Table 2. Results of ExPSO for the 13 benchmark functions (MaxFES =1x10^6)

Unimodal functions

Method	**Result**	f_1	f_2	f_3	f_4	f_5	f_6	f_7
ExPSO	Best	0.00e+00	0.00e+00	0.00e+00	0.00e+00	1.5004e−09	0.00e+00	0.00e+00
	Worst	0.00e+00	0.00e+00	0.00e+00	0.00e+00	4.6777e−06	0.00e+00	0.00e+00
	Avg.	**0.00e+00**	**0.00e+00**	**0.00e+00**	**0.00e+00**	**5.8289e−07**	**0.00e+00**	**0.00e+00**
	S.D.	0.00e+00	0.00e+00	0.00e+00	0.00e+00	1.25961e−06	0.00e+00	0.00e+00
	Avg. FES	141	140	392	197	723262	136	518

Multimodal functions

Method	**Result**	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}
ExPSO	Best	−4.18982e+05	0.00e+00	8.88e−16	0.00e+00	1.6463e−10	1.1401e−09
	Worst	−4.17936e+05	0.00e+00	8.88e−16	0.00e+00	1.3548e−08	6.6937e−07
	Avg.	**−4.18915e+05**	**0.00e+00**	**8.88e−16**	**0.00e+00**	**4.7997e−09**	**3.9678e−08**
	S.D.	2.15931e+03	0.00e+00	0.00e+00	0.00e+00	3.3653e−09	1.2290e−07
	Avg. FES	283804	143	30060	133	85209	267991