Mining Optimization Laboratory

Report Thirteen –2024/2025

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Executive Summary

This year, we have prepared a report including 24 papers under five main topics, as; 1) Open Pit Mining Optimization, 2) Underground mining Optimization, 3) Simulation modeling of Mining Systems, 4) Green Mining, and 5) Other Topics. We continue to update all the research results on the MOL webpage https://sites.ualberta.ca/MOL/ on the members section. Sponsors have access to current and past research results and publications. Let's review the contributions in the MOL Report Thirteen (2024/2025) by considering some of the main contributors.

The first group of papers in this year addressed the development and implementation of different mathematical programming frameworks for long-term and short-term planning, mine design and fleet assignment for open pit mining. The following seven students and postdocs have been the main contributors under this topic:

Alireza in **Paper 101** developed a long-term mine scheduling optimization model for in-pit crushing and conveying (IPCC) that identifies optimal crusher placement and relocation strategies to minimize haulage costs while maximizing Net Present Value (NPV). His methodology uses a two-stage clustering approach (k-medoids followed by hierarchical clustering) to define crusher panels and mining cuts, while explicitly integrating road and conveyor networks to capture realistic material movement. Using real mine data, he demonstrated that the optimized IPCC configurations deliver notable NPV gains and consistently outperform traditional truck–shovel operations across the tested scenarios. He also conducted sensitivity analyses by varying the tonnage processed before crusher relocation and the dollar-per-ton-kilometer haulage cost, showing how throughput levels and changing cost conditions strongly influence relocation decisions, economic robustness, and the overall viability of IPCC as a scalable, sustainable alternative for modern mine planning.

Hongshuo introduced a mixed-integer linear programming (MILP) framework for short-term (weekly) production scheduling in truck–shovel mining systems that explicitly accounts for shovel movement while still meeting ore and total tonnage targets across multiple shovels, as presented in **Paper 102**. Rather than focusing only on grade and tonnage requirements, his model balances allocation across shovels and embeds movement considerations directly in the optimization to reduce unnecessary relocations and preserve productive working time. Applied to a two-shovel, 40-block case study, the optimized schedule cut one shovel's weekly travel distance by 17% relative to a baseline plan that ignores movement, while reallocating longer moves to the other shovel and maintaining overall production goals. The results demonstrate that incorporating movement minimization into short-term schedules can improve equipment utilization and strengthen coordination with downstream processes, producing more operationally efficient mining sequences.

Khaleeq examined how advanced decision-making methods—particularly Deep Reinforcement Learning (DRL)—can be leveraged to improve fleet management in open-pit mining operations, building the discussion around the high cost impact of material handling and haulage, as described in **Paper 103**. His work emphasizes that truck dispatching and shovel allocation strongly influence operating cost and production performance, yet DRL remains relatively underused in mining compared with other industries where reinforcement learning has been applied to complex production control. By reviewing current applications and outlining future opportunities, he clarified where DRL-based dispatching and allocation approaches could complement simulation-based optimization and mixed-integer programming methods, and he highlighted practical considerations and field constraints that need to be addressed for real-world adoption in mine operations.

Nasib developed a simulation–optimization framework that integrates semi-mobile in-pit crushing and conveying (IPCC) into short-term open-pit mine planning while explicitly accounting for operational and equipment uncertainties. In **Paper 104**, his approach combines a mixed-integer linear programming (MILP) model—used to generate cost-minimizing short-term production schedules and optimal shovel-to-cut allocations while meeting long-term production targets—with a Monte Carlo simulation (MCS) haulage model that evaluates schedule performance under uncertainty for trucks, shovels, and IPCC operations, including failure-related disruptions. Using the simulation outputs, he estimated key performance indicators such as maximum tonnes per gross operating hour (TPGOH) and the proximity to optimal production under uncertain conditions, enabling a direct comparison between IPCC and truck–shovel scenarios. Verified through a twelve-month iron ore mine case study, the results provided evidence that semi-mobile IPCC can outperform traditional truck–shovel systems in cost and performance resilience, supporting its practical adoption in uncertainty-aware short-term planning.

Obed developed comprehensive mine design guidelines for effectively integrating Autonomous Haulage Systems (AHS) into open-pit operations, recognizing that conventional design parameters for pit geometry, haul roads, and infrastructure often do not satisfy AHS operational requirements. Drawing on simulation studies, expert interviews, and case study analysis in **Paper 105**, he compared conventional and autonomous haulage scenarios for a 76.4 Mt gold deposit using GEOVIA Whittle, Surpac, and HaulSim, showing that AHS increased material moved by 20.3% over a 168-hour period, enabled modest reductions in ramp width, and improved overall slope angles. He further demonstrated economic benefits through an NPV increase in the modeled case and reinforced real-world feasibility using Rio Tinto case evidence on reduced haulage costs and increased annual operating hours. The work translated these findings into actionable design recommendations—such as optimized ramp gradients, reduced berm widths, segregated autonomous vs. manned roadways, and integrated communications with geofencing—while also addressing implementation challenges (capital cost, workforce adaptation, and infrastructure) and recommending piloting, staged deployment, and continuous monitoring to achieve safer, more efficient, and higher-return autonomous mining operations.

Samaneh presented an integrated optimization framework in **Paper 106** that strengthens open-pit production scheduling by embedding key geometric and operational constraints directly into the precedence-constrained production scheduling problem, rather than treating pit design and scheduling as separate steps. In this work, she incorporated requirements such as minimum mining width, block connectivity, and simultaneous horizontal and vertical precedence relationships within a single direct block scheduling model, with the objective of maximizing net present value while ensuring spatially realistic extraction patterns and smooth pit geometries. The model also accounts for operational considerations including block sequencing, pushback formation, and block accessibility, producing schedules designed to be practical and safe to execute. Validated on benchmark datasets, her approach generated feasible, cavity-free schedules with consistent pit slopes and improved economic performance compared to conventional two-stage pit design and scheduling workflows, offering a scalable methodology for producing geometrically consistent and operationally implementable mine schedules.

Vahid developed a stochastic optimization framework for short-term ore blending that targets consistent feed grade and tonnage to support stable, efficient processing in industrial salt mining, where sodium sulfate is the main product and impurity control is complicated by nonlinear geological variability and energy limitations. In **Paper 107**, he combined Sample Average Approximation (SAA) with a derivative-free pattern search algorithm to optimize impurity-sensitive blending decisions under uncertainty, evaluating 1,000 geological realizations across three mining faces with distinct chemical compositions. Using a nonlinear objective based on normalized deviations from grade and tonnage targets, his approach rapidly solved the resulting non-smooth, high-dimensional problem (with each optimization run completing in under one second) and, when applied at an operating salt mine, improved feed consistency, energy efficiency, and resource sustainability relative to rule-based blending. The framework also helped avoid premature depletion of high-grade zones, strengthening long-term resilience, and was supported by clear implementation procedures, performance metrics, and validation results demonstrating practical robustness.

The second group of papers investigated the optimization of underground mining. The following four students and researchers have been the main contributors under this topic:

Eyram evaluated the most suitable mining method for Block 2 at Auptism Underground Mine (AUM)—a discontinuous, vein-hosted gold zone whose geometry and depth could limit the operational and economic effectiveness of longhole open stoping—by applying a structured, two-phase selection workflow. In this work in **Paper 201**, he first screened alternatives using the University of British Columbia (UBC) mining method selection system based on Block 2's geologic and geometric characteristics, identifying sublevel stoping, shrinkage stoping, and cut-and-fill as candidates, then excluding shrinkage stoping from final consideration due to prior safety-driven discontinuation at AUM. In the final phase, he compared open stoping and cut-and-fill on economic performance and found cut-and-fill to be superior, delivering about 30% higher net profit and a lower unit operating cost ($337/t versus $473/t). Based on these results, he concluded that cut-and-fill is the most favorable approach for maximizing operational efficiency and economic return for Block 2.

Kwaku presented a genetic-algorithm-based optimization approach in **Paper 202** to solve the integrated underground mine development and production scheduling problem—coordinating stope extraction/backfilling with precedent development activities such as declines, ventilation, ore passes, and operational development—to maximize net present value (NPV). In this work (Paper 202), he implemented a specialized mine-scheduling GA using a real-number literal permutation encoding scheme and evolutionary operators to explore the scheduling search space with NPV as the fitness measure. He verified the method using two case studies on a gold deposit (2.88 Mt, 8 levels, 120 stopes, 26-year mine life, open stope mining): a conventional scheduling case that produced a practical schedule with an NPV of $76.67M, and a second case that incorporated subterranean farming by adopting a primary–secondary stope layout where selected secondary stopes were left void (without backfill) for later agricultural use. The subterranean-farming case achieved an NPV of $74.89M (about a 2% decrease), which he attributed to reduced mining flexibility caused by additional geotechnical constraints required for stability around the voids, while also highlighting the potential for added farming revenue from approximately 8,700 m^2 of created space and broader benefits for reclamation options and food-security-related concerns.

Manso reviewed the key geotechnical complexities associated with transitioning from open-pit to underground mining, a critical phase often triggered by reduced surface viability and the need to access deeper ore. In **Paper 203**, he synthesized peer-reviewed literature into a thematic assessment of geomechanical behavior, excavation sequencing, crown pillar design, and the role of modern monitoring technologies, highlighting major hazards such as stress redistribution, pit slope instability, and crown pillar failure. He identified prominent contributors to failure risk—including hydrogeological mismanagement and insufficient numerical modeling—and emphasized that safer, more economically viable transitions rely on staged excavation strategies, integrated modeling approaches (e.g., FEM/DEM), and adaptive monitoring systems that respond to changing ground conditions. Drawing on global case examples such as Chuquicamata, Palabora, and Ernest Henry, he also pointed to the need for more standardized geotechnical frameworks and noted persistent gaps in predictive modeling and real-time sensing that warrant further multidisciplinary research.

Soroush conducted a computational investigation into how key operational parameters shape system-wide performance in integrated sublevel caving, using an enhanced mixed-integer linear programming (MILP) formulation that jointly coordinates development scheduling, production sequencing, and stockpile management. In **Paper 204**, he tested 48 scenarios over a realistic problem size of 537 mining units and used statistical analysis to show that mining direction is the dominant driver of performance—explaining roughly 79–98% of the variance across evaluated metrics—while the chosen optimality-gap tolerance had a comparatively minor influence. His results indicated that a middle-out mining direction yields substantial benefits, producing higher net present value than left-to-right and right-to-left alternatives and improving processing plant utilization. To make the large integrated problem computationally practical, he applied an enhanced Big Block decomposition approach that solved the scenarios within minutes, and he quantified the potential economic risk of relying on simplified, non-integrated models by demonstrating a large gap in value relative to integrated optimization. Overall, the study highlights that upstream extraction decisions can strongly affect downstream processing outcomes and provides actionable guidance for planning tightly coupled mining production stages.

The third group of papers consider simulation modeling of mining systems. The following students have contributed under this topic:

Emmanuel evaluated how intersection traffic-control rules influence haulage efficiency in open-pit mining in **Paper 301**, focusing on intersection delays as a major source of lost productivity. In this work, he used HaulSim to simulate real operating conditions and compare three common right-of-way strategies—Loaded Truck First (LTF), Give Way, and 4-way Stop—measuring impacts on cycle time, fuel consumption, carbon emissions, and overall productivity. The results showed that LTF achieved the highest productivity, particularly for smaller trucks, by dynamically prioritizing ore-loaded and empty trucks while selectively delaying waste trucks, whereas the Give Way rule performed strongly (notably for larger trucks) by smoothing traffic flow and reducing idle time, fuel use, and emissions. By contrast, the 4-way Stop approach was consistently the least efficient due to mandatory stops that increased delays, fuel consumption, and emissions. Overall, his findings demonstrate that replacing rigid intersection protocols with dynamic rules like LTF or Give Way can reduce bottlenecks, shorten cycle times, and lower operating costs, providing practical guidance for fleet management and mine planning.

Mohammad implemented a high-level hybrid simulation framework for truck–shovel haulage in open-pit mining using AnyLogic, designed as a flexible platform for experimentation and future digital-twin applications in **Paper 302**. He combined agent-based and discrete-event simulation to capture haulage dynamics under varying road grades, truck loading strategies, and speed configurations informed by rimpull–retard curves, linking geometric, operational, and behavioral elements within one model. The initial results demonstrated the feasibility of applying AnyLogic to large-scale mining logistics and highlighted how the framework can support mine operations research through scenario testing and system-level performance evaluation. He also outlined forward-looking extensions—such as reinforcement learning, data-driven optimization, and predictive digital twins—to evolve the framework toward intelligent, adaptive decision support for real-time mining operations.

Vahid developed a high-fidelity digital twin of a full open-pit oil sands operation to reduce capital decision risk by enabling systematic, quantitative comparison of major development alternatives. In this **Paper 303**, he introduced a novel "ore-to-barrel" Discrete Event Simulation (DES) model that holistically represents both in-pit and plant processes, integrating key dynamic drivers such as equipment downtime, haulage network logistics, real-time dispatching logic, and material grade tracking. Using the digital twin to evaluate competing capital expenditure scenarios—including options like Autonomous Haulage Systems (AHS), shifts toward continuous haulage, and alternative plant layouts—he generated operational KPIs, identified bottlenecks, and quantified trade-offs across scenarios. The scenario analyses indicated substantial potential operational improvements, including a 15–25% reduction in required truck fleet size relative to the current configuration and associated reductions in average crusher queue times on the order of 20–70%. Overall, the work demonstrates how full-scale digital twins can function as practical decision-support systems for optimizing capital-intensive mining development plans and transparently assessing system-level consequences before committing investment.

Yaa reviewed how combining discrete-event simulation (DES) with game theory can strengthen operational-level decision-making in mining systems, where productivity is shaped not only by stochastic events but also by the strategic behavior of human and organizational agents. In **Paper 304**, she discussed how DES can represent the cyclical, uncertain dynamics of mine operations—such as cycle times, queuing, breakdowns, and dispatching strategies—while game theory can model strategic interactions and trade-offs among operational players including shovel operators, truck operators, and maintenance/dispatch teams. By connecting these perspectives, her review highlighted how agent decisions and incentives can be analyzed alongside scenario-testing capabilities in DES to identify more robust, operationally realistic policies. Overall, the paper provides a conceptual pathway for integrating behavioral strategy with simulation-based experimentation to support better-informed and more effective decisions in day-to-day mining operations.

The fourth group of works this year investigated some aspects of environmental considerations in different stages under green mining, including mine closure, reclamation, and post-mining land use, energy consumption and greenhouse gas (GHG) emissions, energy consumption and respirable dust generation. The following six students have contributed under this topic:

Cristina presented a reproducible conversion method that helps decarbonization studies translate diesel-based discrete-event haulage simulation outputs into defensible estimates for battery-electric (BEV) and trolley-assisted haulage performance. Her framework in **Paper 401** converts standard simulator outputs—cycle times, travel distances, state durations, payloads, and fuel consumption—into per-truck electrical demand, state-of-charge trajectories, charging requirements, and productivity metrics, while explicitly accounting for route geometry and duty-cycle structure, dynamic trolley energy supply along catenary segments, and regenerative braking on downhill legs. She also enabled scenario analysis and sensitivity studies over battery capacity, charger power, and trolley coverage to compare baseline diesel operations with hypothetical electrified alternatives. Demonstrated on an industrial-scale haulage case, the method showed how per-cycle energy demand, charger sizing, and catenary extent jointly shape operational feasibility and highlighted key trade-offs between productivity and emissions, providing a transparent baseline for sites to assess electrification pathways before investing in detailed electric-fleet simulations or field trials.

Jabar conducted a systematic review of mine closure, reclamation, and post-mining land use research to address how mining legacies can be transformed into ecological and socio-economic assets in the context of rising critical-minerals demand. In **Paper 402**, he synthesized evidence from 124 peer-reviewed studies using PRISMA-guided screening and analysis of literature from Scopus, Web of Science, and IEEE Xplore, applying thematic coding and comparative case assessment to extract practical lessons and gaps. The review highlighted that early-stage closure planning—such as slope stabilization, in-pit tailings disposal, and hydrological re-routing—can reduce long-term remediation costs and risks, and it emphasized the growing value of AI tools including LiDAR–InSAR monitoring and ensemble-learning models that can achieve high predictive accuracy for geotechnical failures. He also summarized integrated ecological interventions (e.g., biochar amendment, geomorphic reconstruction, and phytoremediation) that can accelerate biodiversity recovery over time, and proposed an AI-enabled, circular-economy framework aligned with the SDGs that prioritizes open data governance and stakeholder co-design. Overall, his framework positions post-mining landscapes for productive reuse—such as renewable energy developments, eco-tourism zones, and research parks—supporting climate-aligned transitions, local diversification, and sustained environmental recovery.

Joshua examined how energy consumption patterns drive greenhouse gas (GHG) emissions in Ghana's metal mining sector and assessed how national climate policy frameworks translate into practice within the industry in **Paper 403**. In his work, he used secondary data from selected mining firms and applied statistical and regression analyses to quantify the relationship between energy use from electricity and diesel and the resulting emissions, showing a clear positive link and identifying diesel as the dominant contributor with a stronger effect than electricity. He further discussed how Ghana's National Climate Change Policy and commitments under the Paris Agreement provide a basis for emissions reduction, while noting gaps in implementation specific to mining. Building on these findings, he highlighted that mines with greater reliance on grid electricity and natural gas, alongside stronger energy efficiency, tend to produce fewer emissions, and he recommended that companies adopt energy-efficient technologies and increase renewable energy use while aligning with Ghana's mitigation strategies. He also emphasized the role of government in strengthening regulations and providing incentives to accelerate adoption of low-carbon technologies, positioning the study as an empirical resource for both policymakers and industry stakeholders pursuing more sustainable mining energy practices.

Manso provided full-scale experimental evidence showing how conical pick wear at the cutting face drives both higher cutting energy and greater respirable dust generation in mechanized coal mining, in the context of tightening silica exposure limits and stronger regulatory emphasis on dust control. In **Paper 404**, he performed controlled linear cutting tests on bituminous coal using continuous-miner conical picks at three wear stages, keeping penetration, feed rate, and spacing constant to isolate wear effects; he calculated specific energy from measured cutting forces and collected airborne respirable dust using NIOSH-standard sampling methods for both gravimetric mass and crystalline silica. The results demonstrated a strong degradation in efficiency as picks wore, with specific energy increasing from about 15.11 to 38.49 $hp \cdot hr/yd^3$ and respirable dust concentrations rising from roughly 19.39 to 54.02 mg/m^3 from new to worn picks. Regression analysis showed a strong linear relationship between dust concentration, specific energy, and pick tip radius, reinforcing a reproducible quantitative link between tool wear, energy demand, and dust emissions. Overall, the study highlights that pick wear can substantially elevate health and safety risks while increasing energy consumption, and it offers practical benchmarks to support predictive maintenance and more effective dust-control strategies within the NIOSH Smart Bit Project context.

Md Shehab carried out a PRISMA-guided systematic review to clarify the environmental implications of transitioning mines from open-pit to underground extraction as near-surface deposits become depleted. In **Paper 405**, he screened literature from 2010–2025 and identified 30 relevant publications on open pit-to-underground (OP–UG) transitions, synthesizing impacts across land, water, air, energy, and community dimensions to provide a cross-domain perspective rather than treating these issues in isolation. The review emphasized the land-use benefits of reduced surface disturbance, while also highlighting new challenges—most notably the substantially higher energy demand for underground ventilation, which can account for a large share of total mine power use, with ventilation-on-demand approaches offering meaningful reductions. He also discussed socio-environmental trade-offs: OP–UG transitions can extend mine life and employment, but they can complicate land-use decisions and closure planning for nearby communities. Finally, he identified major gaps such as the lack of comprehensive sustainability models for OP–UG transitions and pointed to emerging solutions—like IoT sensor networks and ventilation-focused digital twins—as promising tools to improve real-time monitoring, energy efficiency, and safety, concluding that integrated environmental management is essential for net-positive, sustainability-aligned transition outcomes.

Somayeh provided a comprehensive synthesis of mine reclamation and post-mining land use research that brings together legislative frameworks, methodological advances, persistent challenges, and key directions for future work. In **Paper 406**, she systematically selected and reviewed more than forty peer-reviewed studies and policy documents from Scopus, Web of Science, and Google Scholar using focused reclamation and land-use keywords, prioritizing research from 2000–2024 and excluding sources lacking methodological rigor or field validation to keep the findings practically relevant. Her review highlighted a global shift toward integrated, site-specific reclamation planning that uses multi-criteria decision-making tools—such as PROMETHEE-SIR and SWOT-C—together with ecological and socio-political indicators to guide land-use outcomes. At the same time, she identified recurring gaps in long-term monitoring, incorporation of Indigenous knowledge, and climate-resilient reclamation design, along with constraints created by inconsistent financial assurance and regulatory mechanisms, particularly in developing regions. Overall, she emphasized the need for stronger interdisciplinary collaboration, better policy incentives, and improved data transparency to support sustainable, inclusive, and economically viable post-mining landscape frameworks.

Finally, the last group of works this year includes the following three papers about geochemical anomaly patterns recognition, Selective Mining Unit (SMU) optimization, and solving optimization models on high-performance computing (HPC) systems.

Iman addressed the challenge of identifying mineralization-related geochemical anomalies in data-scarce, geologically complex greenfield exploration by combining machine learning with compositional data treatment to improve detection of subtle multivariate signals linked to gold. In **Paper 501**, he integrated One-Class Support Vector Machines (OCSVM) with Compositional Data Analysis (CoDA), applying centered log-ratio (CLR) and isometric log-ratio (ILR) transformations to mitigate the closure problem and map geochemical compositions into Euclidean space prior to modeling. He trained RBF-kernel OCSVM models on raw, CLR-transformed, and ILR-transformed datasets, then spatially mapped anomaly scores and validated them against linear productivity (LP) indices derived from borehole drilling, using ROC analysis to quantify predictive performance. Using 604 lithogeochemical samples and 57 drillholes from the Khunik prospect in southeastern Iran, he showed that compositional preprocessing improved anomaly recognition, with ILR achieving the best performance (AUC = 0.708), followed closely by CLR (AUC = 0.704), both outperforming raw data (AUC = 0.635). He also tested robustness by injecting controlled noise into the datasets, reinforcing that the CoDA–OCSVM integration provides a more sensitive and reliable anomaly detection framework for exploration targeting in complex settings.

Noaman investigated how Selective Mining Unit (SMU) size influences ore–waste classification, dilution, ore loss, and overall economic performance, and proposed a data-driven approach to identify an SMU dimension that balances geological selectivity with operational profitability. In **Paper 502**, he introduced a quantitative framework that combines geostatistical uncertainty modeling with economic evaluation by applying Sequential Gaussian Simulation (SGS) to exploratory drillhole data to generate multiple probabilistic copper-grade realizations, then validating these against a deterministic blast-hole model. He classified blocks as ore, waste, dilution, or ore loss using several cutoff grades and assessed performance across different SMU sizes using metrics such as classification accuracy, ore recovery, probability-weighted grades, and economic indicators including net profit and profit per tonne moved and processed. Using a multi-criteria decision process to trade off misclassification versus value, he identified an SMU of 40 × 40 × 15 m as the most effective compromise, reducing classification errors while maintaining recovery and profitability. Overall, the framework offers a practical probabilistic tool to improve long-term resource evaluation and reduce design uncertainty linked to SMU selection.

Yashar provided a practical tutorial that introduces high-performance computing (HPC) for mining engineers and researchers who want to leverage modern computational resources to solve complex mining problems more efficiently. In **Paper 503**, he first outlined what HPC is and why it has become increasingly important beyond computer science, then explained foundational concepts such as cluster architecture, common HPC terminology, and the role of resource scheduling in shared computing environments. He further detailed how resource scheduling works in practice and walked through job submission procedures, giving readers a clearer path from understanding HPC infrastructure to actually running workloads on clusters. By framing the tutorial around mining engineering needs—especially computationally intensive mathematical optimization—his paper equips practitioners with the essential knowledge to begin using HPC tools and workflows to accelerate research and operational decision-support applications.

We extend our gratitude to all the contributors who played a crucial role in preparing the 2025 MOL Report. This includes the dedicated faculty members from three universities, the graduate students, postdoctoral fellows, alumni, and industrial/consultant affiliates. Special thanks to ***Liane Tse Tse*** for her tireless efforts as the administrative assistant in proofreading and editorial revisions, ensuring the highest quality of this report. Your collective contributions have been invaluable.

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December 2025

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Mining Optimization Laboratory (MOL) Researchers / Graduate Students

Following are researchers and students affiliated with Mining Optimization Laboratory in December 2025.

1.	**Hooman Askari-Nasab**	Professor - Director of MOL
2.	**Eugene Ben-Awuah**	Professor, Laurentian University
3.	**Yashar Pourrahimian**	Professor, University of Alberta
4.	**Ali Moradi Afrapoli**	Assistant Professor, University of Kentucky

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5.	**M. Mahdi Badiozamani**	PhD, Research Associate - 2018/03
6.	**Hongshuo Gong**	PhD, Post Doctoral Fellow - 2024/01
7.	**Alireza Kamrani**	PhD, Post Doctoral Fellow – 2025/01
8.	**Emmanuel Appianing**	PhD, Post Doctoral Fellow – 2025/01
9.	**Minoo Hosseinzadeh**	PhD, Post Doctoral Fellow - 2025/09
10.	**Mojtaba Yeganejou**	PhD, Post Doctoral Fellow – 2025/10
11.	**Soroush Khazaei**	PhD, Post Doctoral Fellow – 2025/12
12.	**Samaneh Moradi Pirbalouti**	PhD Student – 2022/09
13.	**Khaleeq Ahmed**	PhD Student – 2023/01
14.	**Mohammad Al-Masri**	PhD Student – 2024/09
15.	**Md Shehab Islam**	PhD Student – 2025/01
16.	**Manso Sesay**	PhD Student – 2025/09
17.	**Solomon Acheampong**	PhD Student – 2025/09
18.	**Yaa Karikari**	MSc Student – 2023/01
19.	**Kwaku Konadu Akuffo**	MSc Student – 2023/09
20.	**Cristina E. Miranda B**	MSc Student – 2024/01
21.	**Asmita Karki**	MSc Student – 2025/09
22.	**James Agyarko-Mensah**	MSc Student – 2025/09