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Integration of Engineering Graduate Attributes with Lean Manufacturing to Enhance Work and Education Systems: Industrial Engineering Field, South Africa

Matshidiso Moso
Doctor, Industrial Engineering Department
Industrial Engineering lecturer
Durban University of Technology
Durban, South Africa
matshidisom@dut.ac.za

Okuhle Ndlovu
Student, Industrial Engineering Department
Group leader, Engineering Work Systems III
Durban University of Technology
Durban, South Africa
22115134@dut4life.ac.za

Abstract

Teaching and learning in higher institutes of engineering colleges has shifted away from work-integrated learning, which is used to equip students with practical knowledge of real-world problem-solving. Hence, there is a need for industry collaboration in one of the course modules. In this research, the University collaborated with Industry partners to improve the quality of engineering students it produces. The main objective was to produce adaptive graduates; hence, the graduate attribute project was set using industry real problems. The production bottlenecks are caused by misalignment with high-speed primary packaging outputs. Systemic engineering techniques, including process mapping, time and work studies, modelling, simulation, and workflow analysis, were applied to identify performance gaps and inefficiencies across the packaging line. Lean tools such as 5S, Kaizen, and Poka-Yoke were incorporated alongside automation technologies to redesign and improve the system. The proposed solution features sensor-based counting systems, automated defect detection, ergonomically optimized workstations, and synchronized conveyor operations to ensure continuous product flow and accuracy. The integration of GA5 technical analysis with Lean optimization demonstrated measurable improvements in productivity, operational efficiency, and quality consistency. Furthermore, waste levels, rework, and labor strain were significantly reduced, contributing to lower operational costs. Overall, the combined approach establishes a more sustainable, reliable, and high-performance secondary packaging environment aligned with modern food manufacturing standards and continuous improvement objectives.

Keywords
Lean Manufacturing, GA5 Engineering Tools, Packaging Automation, Process Optimization, Productivity Improvement

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1. Introduction

The engineering field is a discipline that is based on critical thinking skills and solving complex problems(Lavi & Marti, 2023)The Industrial Engineering field is specifically based on optimizing processes, simplifying processes, evaluating continual improvement of systems for profitability purposes, hence business sustainability (Shil, 2023). The South African Engineering field is regulated by the Engineering institute, which regulates Engineering from the Universities to the personal profession. The universities are guided by the Engineering Counsel which has its own protocol for graduates(Sibanda & Naidoo, 2024). Each University must comply with the requirements and specifications of the engineering programs. If the student has fulfilled the graduate attributes, they then qualify to graduate. This research seeks to leverage the Engineering Graduate Attributes by incorporating Industry based project using lean manufacturing techniques within the Industrial Engineering field. The current methods will be reviewed, and the structured lean-based project to improve graduate adaptabilities in Industries will be implemented, and the results will be evaluated.

2. Related work

Shahin et al. 2024(Shahin et al., 2024) Evaluated that Lean manufacturing can be utilized in different approaches, including repairing, inventing, maintaining, and predicting a process. Ghaithan et al. 2023(Ghaithan et al., 2023) Further examined that Lean manufacturing is used to optimize the system for better performance and sustainability of an organization. Engineering education is practical and more technical; it requires technical projects, preferably industry-based projects, which align with the Engineering professional bodies(Naseer et al., 2025).Engineering professional bodies emphasize the industry collaborated project to enhance the technical capabilities, especially in the universities of Technology hence a need of advanced tools of project-based learning(Llopis-Albert et al., 2025).On this review Engineering project based tools and models to enhance preparedness of students for industrial projects will be reviewed.

A study to upskill the students with latest technologies related to industry 4.0 was conducted, a model composed of combined substantial based educational industry related projects was developed and adopted to carry out the study. These live projects were conducted in various manufacturing industries to enhance teaching and learning in an engineering college. The project resulted in drastic improvements, especially in Engineering-based education. The students were equipped with real-life problems and upgraded their ability to improve industrial processes (Bondin & Zammit, 2025). A review was conducted to evaluate recent technologies used to train students and workers, preparing them for real-world manufacturing processes. The 5W1H (Where, Who, When, Why, How) approach was used to carry out the study. It was found that Virtual Reality-based training is the best strategy for industry work preparedness training, and it is an evolving strategy for both industries and Universities for advanced manufacturing skills(Ipsita et al., 2025).

Even though there are virtual tools for manufacturing work preparedness training, it has been found that hybrid teamwork-based learning is much more effective than individual virtual reality learning tools(Singh et al., 2025). Analyses were carried out to evaluate the use of virtual reality-based learning in groups to improve teamwork and to enforce brainstorming for problem-solving techniques within manufacturing sectors due to the complexity of the industry. A mixed reality training module was proposed. The proposed module was flexible for multi-use purposes, which allowed multidisciplinary projects to be combined, hence more effective ideas and advanced manufacturing solutions(Doolani et al., 2020).

Ramos et al. 2023 (Ramos et al., 2023) Examined that to enhance Engineering education, students should be equipped at their exit level for work preparedness projects by introducing them to the complex real-life problems faced by manufacturing sectors. Research was conducted to keep the industry 4.0 concepts evolving in the manufacturing sectors by improving the techniques and educational resources to train for work preparedness. Virtual Reality technology-based learning was applied to advance the manufacturing skills and tested, it was found that the proposed method equipped students with more knowledge and capabilities to solve complex problems, and the effectiveness of 25% compared to the old training methods(Bano et al., 2024).

Engineering Graduate attributes are compiled and issued by the Common Institute of Engineering per specific field. These graduate attributes examine the students' capability for academic progress, hence the need for a program covering the work preparedness scope (Gamage et al., 2023). Lai et al 2025 (Lai et al., 2025) Evaluated that Career preparedness is the most crucial part for exit-level undergraduate students across different fields, especially in the technical and most practical fields. The Engineering field is one of the most practical and technical fields which requires industry exposure and best practical exposure. The graduates' attributes normally focus on the academic based requirements to prepare the student in this study, the context of Industry preparedness scope was reviewed to pilot the understanding of work readiness. A survey was conducted to the recent Engineering graduates to test their knowledge. It was found that even though work readiness is understood by most graduate but there is a lack of industry-based knowledge and capability in real-life problem-solving(Deters et al., 2024). A study was conducted to examine the gap for work readiness in most Universities in India ,data sampling was used for analysis it was found that the students lacked problem-solving skills of the industrial complexity and a need for industry collaborations with universities was identified (Hoque et al., 2023).

An analysis to improve the Engineering education exit program was conducted. This research aimed to equip undergraduate students with real-world problem-solving technical skills for work readiness. A real-world problem was identified, and the students were tasked to develop a smart electronic system, and the effectiveness of the projects to students was evaluated by a survey. The students indicated a positive impact on their understanding of industry-related problems and felt prepared and ready to face real world Engineering problems(Ghannam & Chan, 2023). A study was conducted on civil engineering students, evaluating their capabilities to adapt easily to solving industrial problems. A questionnaire was developed, and industry representatives were tasked to engage and complete the questionnaire. It was found that even though the students are academically equipped, they still lack some industry-related problem-solving skills, hence the need for industrial collaboration with the universities (Rajput et al., 2024). Research was carried out for mechanical Engineering students to test the best teaching and learning strategy that will prepare students to be ready for real-world work environment-solving techniques. Both traditional methods, which are more theoretical, and the practical method were applied. It was found that the practical-based methods in the laboratory and school workshop made different students understand much better when applying knowledge and practical, but a need for industry collaboration was identified since the students were lacking some of the work preparedness skills (Inderanata & Sukardi, 2023).

As technology evolves, it is important to align graduate attributes with relevant industrial revolution technology(Seti et al., 2025). An investigation based on Industrial Engineering post-graduates work preparedness in Brazil was conducted data sampling method was adopted for this study, where different Universities were evaluated, and it was found that even though Universities has improved from traditional methods, the students still lack some work readiness skills, like commercialization of research, leadership skills, and other real-world problem-solving industrial-related techniques(Tortorella et al., 2023).Covid-19 has impacted teaching and learning negatively, especially in the Engineering field due to the technical and practical nature of the field, such affect the students readiness to go work to the manufacturing sectors(Chasciar et al., 2025). A study to evaluate the impact of COVID-19 teaching and learning methodology, which was digitally based versus practical and work preparedness, was examined in this study several industry and retail partners were interviewed it was found that there is still a need for universities to incorporate the Work Integrated Learning within the modules(Mkhize & Reddy, 2025)

3. Gap Analysis and findings from literature

The reviewed literature highlights significant progress in integrating lean manufacturing, Industry 4.0 technologies, and project-based learning into engineering education to enhance student work preparedness. However, several critical gaps remain. Studies on lean manufacturing focus predominantly on industrial process optimization rather than educational integration. This review demonstrates its effectiveness in repairing, inventing, maintaining, predicting processes, and improving organizational sustainability. Despite this, the literature does not sufficiently explain how lean principles can be systematically embedded into engineering curricula to prepare students for industry-based projects. The pedagogical translation of lean tools into teaching and learning environments remains underexplored.

The engineering professional bodies emphasize industry-collaborative and project-based learning as essential for developing graduate competencies. While this establishes the importance of practical exposure, there is limited empirical evidence on the specific tools, models, and implementation frameworks required to operationalize advanced project-based learning within universities of technology.

Existing reviews acknowledge the need but do not provide integrated or scalable educational models. Industry 4.0 upskilling initiatives have shown promising results. Live industry projects and substantial industry-based educational models improved students' problem-solving abilities and exposure to real manufacturing challenges. However, these interventions are often context-specific, small-scale, or pilot-based, limiting their generalizability and long-term sustainability within formal curricula.

The emerging technologies such as Virtual Reality, mixed reality, and hybrid simulation tools have been widely studied for manufacturing training. Research indicates that VR enhances advanced manufacturing skills and can improve training effectiveness compared to traditional methods. Nevertheless, several gaps persist. Overreliance on individual VR learning rather than collaborative environments, Limited integration of hybrid teamwork-based learning despite evidence of higher effectiveness, Insufficient multidisciplinary application of mixed-reality modules for complex industrial problem-solving. Thus, while immersive technologies are advancing, their collaborative, interdisciplinary, and curriculum-embedded applications remain underdeveloped. Multiple studies reveal a persistent mismatch between engineering graduate attributes and industry expectations. Surveys of graduates and employers consistently report deficiencies in Real-life industrial problem-solving, Industry-based knowledge, Commercialization skills, Leadership and teamwork competencies.

Although academic programs meet theoretical outcomes, they inadequately address applied industry preparedness. This indicates a structural gap between accreditation requirements and workplace realities. Furthermore, work-integrated and real-world project interventions such as smart system development projects and industry-linked assignments demonstrate positive impacts on student readiness. Yet these initiatives remain isolated interventions rather than institution-wide strategies embedded across engineering programs. Another major gap concerns industry collaboration. Evidence from civil, mechanical, Industrial and multidisciplinary engineering studies confirms that laboratory and workshop practical's improve learning, but they do not fully replicate industrial complexity. Stronger, sustained university-industry partnerships are still lacking. Additionally, the rapid evolution of Industry 4.0 technologies requires continuous alignment between graduate attributes and modern manufacturing practices. Current curricula adaptations lag technological advancement, particularly in areas such as digital manufacturing, smart systems, and automation integration. Finally, the COVID-19 pandemic exposed systemic weaknesses in engineering education delivery. The shift to digital learning negatively affected practical competence and manufacturing readiness. Although virtual learning mitigated disruptions, studies confirm a continued need to reintegrate Work-Integrated Learning (WIL) and hands-on industrial training post-pandemic.

4. Current and existing models

Currently, most universities of technology in South Africa are regulated by the Engineering Council. The Council of Engineering has its own requirements that a student shall adhere to graduation. The graduate attributes are different components and stages that a graduate should go through and progress through until they are all fulfilled(Gericke et al., 2025). These graduate attributes include Engineering knowledge, which refers to the graduate's ability to apply core principles of mathematics, natural sciences, and engineering sciences to practical and theoretical problems. It involves understanding fundamental concepts such as mechanics, materials, thermodynamics, electronics, and systems engineering. Graduates must demonstrate the capacity to integrate theory with practice, perform calculations, develop models, and interpret engineering data. This foundational knowledge underpins all other graduate attributes because it enables engineers to understand, predict, and improve engineering systems.
Problem-solving is one of the graduate attributes which deals with the ability to identify, define, investigate, and analyse complex engineering problems using appropriate methods.

Graduates must be able to break down problems into manageable components, apply logical reasoning, and use evidence-based approaches to reach solutions. This includes diagnosing faults, evaluating alternative solutions, and considering constraints such as cost, safety, and sustainability. Effective problem analysis ensures that engineering decisions are technically sound and contextually appropriate. The Design and Development of Solutions This attribute focuses on the ability to design systems, components, or processes that meet specified needs. Graduates must translate theoretical knowledge and problem analysis into practical designs that are functional, safe, sustainable, and economically viable. The design process includes conceptualization, modelling, simulation, prototyping, testing, and optimization. It also requires consideration of standards, user needs, environmental impact, and manufacturability. The Professional and ethical conduct involves understanding and applying ethical principles, professional standards, and legal responsibilities in engineering practice. Graduates must act with integrity, accountability, and respect for societal values.

This includes maintaining confidentiality, avoiding conflicts of interest, ensuring public safety, and complying with regulatory requirements. Ethical engineers prioritize the welfare of society and the environment in all professional

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decisions. Ethics, as emphasized in the flowchart figure 1, relates specifically to moral decision-making in engineering activities. Graduates must recognize ethical dilemmas, evaluate consequences, and choose actions aligned with professional codes of conduct. This includes honesty in reporting data, responsible use of resources, and fairness in professional interactions. Ethical awareness strengthens public trust in engineering practice. Engineering impact refers to understanding how engineering solutions affect society, industry, and the environment. Graduates must evaluate the social, economic, cultural, and environmental consequences of projects. This includes sustainability considerations, environmental protection, community welfare, and long-term societal benefits. Engineers are expected to design solutions that are responsible, inclusive, and sustainable.

Project management involves planning, organizing, directing, and controlling engineering projects. Graduates must understand budgeting, scheduling, risk management, resource allocation, and quality control. Leadership skills are also essential, as engineers often supervise teams and coordinate multidisciplinary activities. Effective project management ensures projects are completed on time, within cost, and according to specifications. Modern tool usage refers to the ability to select and apply appropriate engineering tools, software, and technologies. This includes computer-aided design (CAD), simulation software, data analysis tools, automation systems, and digital manufacturing technologies. Graduates must also understand the limitations of these tools and apply them responsibly to solve engineering problems efficiently. Teamwork is the ability to function effectively as an individual and as a member or leader of diverse teams. Engineering projects are rarely completed alone; they require collaboration across disciplines. Graduates must demonstrate interpersonal skills, conflict resolution, coordination, and shared responsibility to achieve project objectives.

Communication involves the ability to convey engineering information clearly and effectively through written reports, technical drawings, presentations, and verbal discussions. Graduates must communicate with engineers, clients, policymakers, and the public. Strong communication ensures that technical concepts are understood, decisions are documented, and projects are executed accurately. Lifelong learning reflects the recognition that engineering knowledge continuously evolves. Graduates must be self-directed learners who seek ongoing professional development. This includes adapting to new technologies, pursuing further education, attending training, and staying updated with industry trends. Independence and responsibility highlight the engineer's accountability for personal growth and professional competence throughout their career. Figure 1 Illustrate the graduates attributes overview of the Engineering Counsel of South Africa.

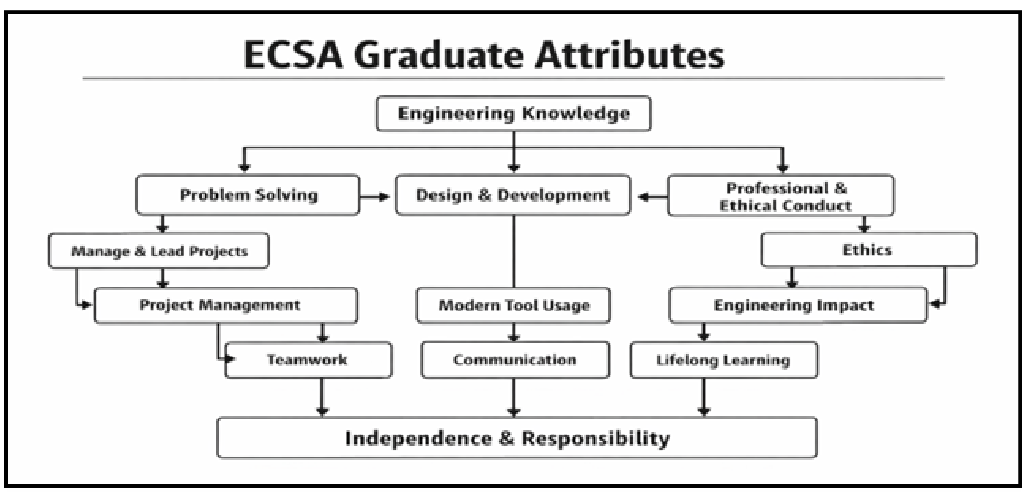

Figure 1: An illustration of the ECSA graduates' attributes framework
Source:(for & 2023)

4.1 Proposed models

GA5 Engineering Methods, Skills, and Tools including IT, modelling, simulation, and analysis, represent the application of engineering knowledge and digital technologies to analyse, design, and improve manufacturing systems. Information Technology supports real-time data collection, monitoring, and automation; while modelling and simulation enable engineers to test and validate process improvements virtually before physical implementation. Analytical methods further assist in evaluating key performance indicators such as cycle time, throughput, and defect rates, forming a strong technical foundation for integrating Lean Manufacturing techniques within production environments such as secondary packaging. Lean Manufacturing Principles focus on maximizing customer value while minimizing waste by producing only what is required, when it is required, and in the correct quantity. Concepts such as value stream thinking, continuous flow, pull systems, and the pursuit of perfection guide organizations in streamlining operations. Supporting these principles, Process Mapping visually documents each step in the workflow, allowing engineers to track the movement of materials and information, identify bottlenecks, and eliminate non-value-adding activities particularly useful in analyzing delays between wrapping, boxing, and palletizing in the Fizzer Toffees secondary packaging line. Waste Elimination (MUDA) targets the seven classic wastes overproduction, waiting, transport, over-processing, inventory, motion, and defects thereby improving efficiency and reducing operational costs, for example by minimizing unnecessary carton movement, machine idle time, and sealing defects.

Time and Work-Study complements this by measuring task durations and evaluating operator motions to establish standard times and best practices, ensuring efficient and ergonomically safe loading, sealing, and stacking operations. Line Balancing further enhances flow by distributing tasks evenly across workstations, so each operates at similar capacity, preventing bottlenecks and idle time while synchronizing wrapping, counting, boxing, and sealing activities. Continuous Improvement (Kaizen) embeds a culture of ongoing, incremental enhancements involving all employees, where small changes such as workstation layout adjustments or tool repositioning collectively improve productivity and safety. Process Optimization then applies engineering analysis and lean data to refine workflows for maximum performance, including machine setting adjustments, layout redesign, and automation of manual steps, often validated through GA5 simulation tools. The integration of these GA5 tools and Lean techniques is realized in the Secondary Packaging of Fizzer Toffees, where data-driven engineering analysis supports lean implementation, improves equipment utilization, and ensures packaging operations meet production targets systematically and sustainably. As a result, the system achieves Increased Productivity through higher output rates and reduced delays, Reduced Waste and Cost through lower material loss, rework, and energy consumption, and Improved Quality and Efficiency via standardized work, optimized processes, and consistent packaging performance.

The combination of GA5 Engineering Methods, Skills & Tools with Lean Manufacturing techniques in the Secondary Packaging process for Fizzer Toffees delivers significant operational and strategic benefits. By integrating IT, modelling, simulation, and analytical tools with lean practices such as process mapping, waste elimination, time study, line balancing, Kaizen, and process optimization, the packaging system becomes more data-driven, efficient, and responsive. This model enables organizations to identify inefficiencies quickly, test improvements virtually, and implement the most effective solutions with minimal disruption. As a result, productivity increases through smoother workflow, balanced operations, and reduced downtime. At the same time, waste and operational costs decline due to better material usage, fewer defects, lower rework levels, and optimized labor deployment. Furthermore, standardized processes and continuous monitoring enhance product quality, packaging consistency, and overall system reliability. Collectively, this integrated approach strengthens manufacturing efficiency, supports continuous improvement, and enhances the organization's ability to meet customer demand competitively and sustainably. Figure 2 is an illustration of the relationship and the integration of Lean manufacturing tools with Graduate Attribute 5 (GA 5).

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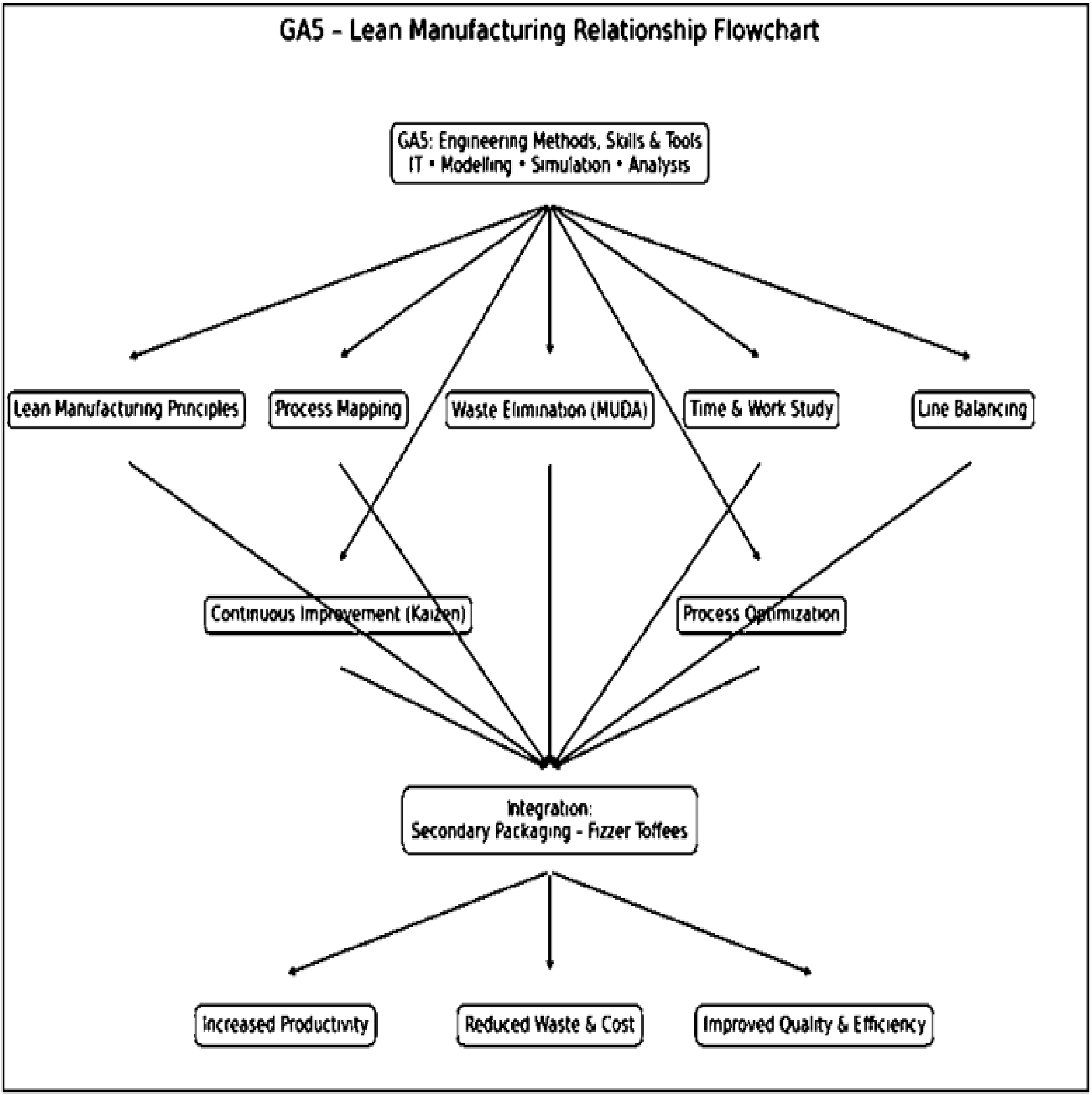

Figure 2. Illustration of the relationship and the integration of Lean manufacturing and GA 5
Source: [Author]

5. Results and Discussion

This project focuses on improving efficiency, quality, and productivity in the secondary packaging operations of Fizzer Toffees. Using Lean Manufacturing and systemic engineering approaches, the study redesigns the packaging workflow to align with modern manufacturing performance standards. The problem identified was that manual counting and packing created miscounts, defects, worker fatigue, bottlenecks, and reduced throughput especially due to the mismatch between high-speed primary packaging and slower secondary processes.

Key findings showed that manual operations led to inaccuracies, waste, ergonomic strain, and workflow imbalances. Process mapping and time studies confirmed bottlenecks and uneven task distribution, while environmental factors also affected packaging quality.

To address these issues, the project proposes an automated secondary packaging system featuring sensor-based counting, defect detection, synchronized conveyor flow, ergonomic workstation design, and lean layout optimization supported by simulation modelling.

Overall, integrating automation with Lean principles such as 5S, Kaizen, and Poka-Yoke significantly enhances productivity, reduces waste and human error, improves product quality, and creates a more sustainable and efficient packaging system. Key recommendations include implementing automated counting and inspection, improving workplace organization and ergonomics, introducing temperature control, and synchronizing primary and secondary packaging lines. Figure 3 is an illustration of the automated packaging system proposed by the students.

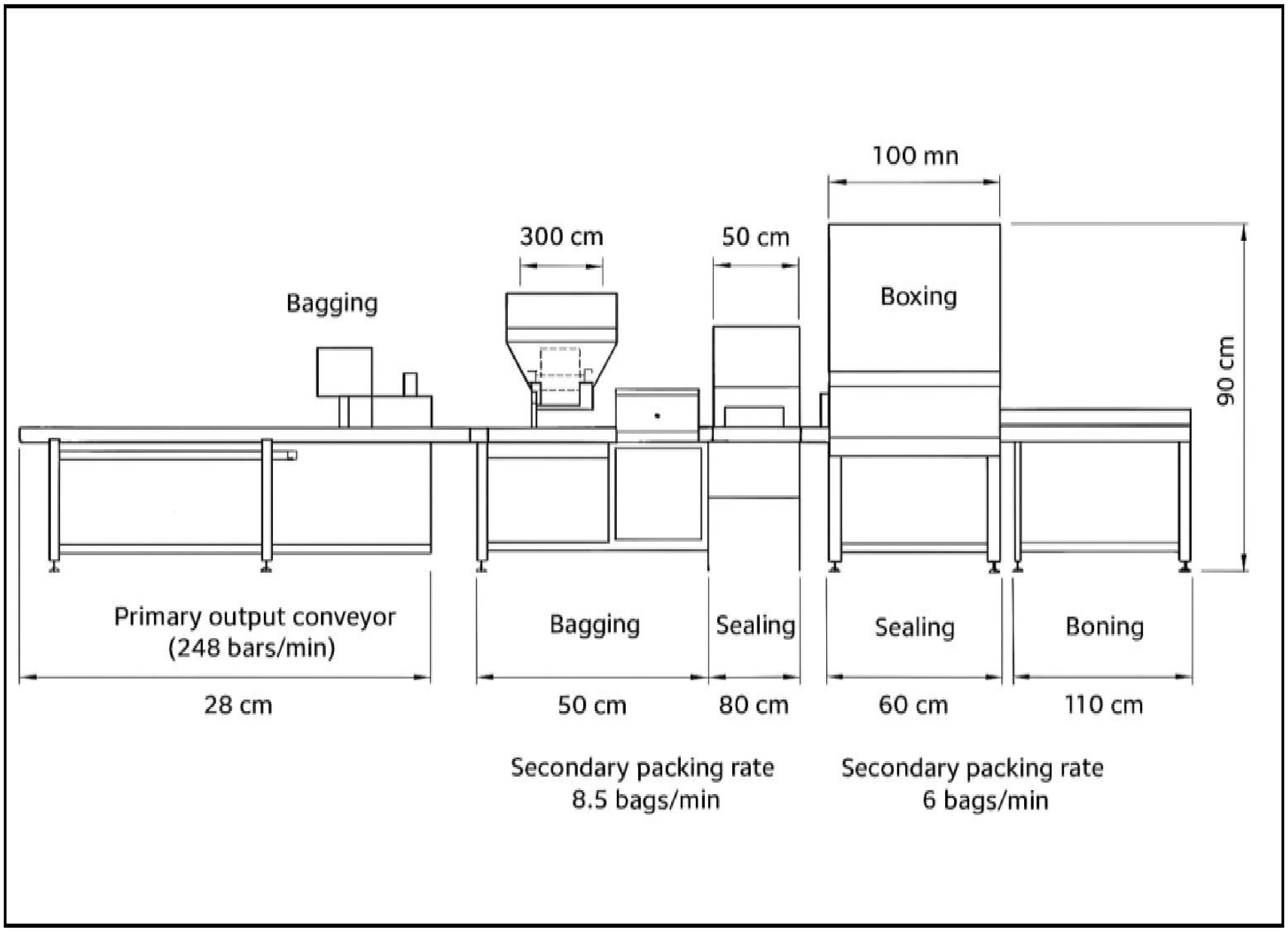

Figure 3. Illustration of an automated packaging system
Source: [Engineering Work Systems students]

6. Recommendations and Conclusion

Based on the project findings and the benefits realized from combining GA5 engineering methods with Lean Manufacturing principles, several key recommendations are proposed to enhance the secondary packaging process. Sensor-based automated counting systems should be implemented to eliminate manual miscounts, while automated defect detection technologies must be installed to strengthen quality control. The application of 5S workplace organization will improve efficiency and reduce motion waste, supported by ergonomically redesigned workstations that minimize worker fatigue and enhance operator safety. In addition, temperature-controlled packaging zones should be introduced to maintain product integrity, and primary and secondary packaging line speeds must be synchronized to remove production bottlenecks. To sustain and continuously improve system performance, simulation and modelling tools should be utilized for ongoing process optimization, alongside the establishment of Kaizen continuous improvement teams to drive long-term operational excellence.

The study demonstrates that integrating GA5 engineering tools with Lean Manufacturing principles provides an effective framework for optimizing secondary packaging operations. Engineering modelling, simulation, and analytical methods enabled data-driven decision-making, while Lean practices addressed inefficiencies within workflow design and labor utilization. The transition from manual to automated counting and packing reduced human error, improved throughput, and eliminated bottlenecks between primary and secondary packaging stages. Furthermore, ergonomic improvements minimized worker fatigue, enhancing both safety and performance. Overall, the combined GA5-Lean approach delivered measurable gains in productivity, quality consistency, waste reduction, and operational sustainability, confirming the value of systemic, technology-supported Lean implementation in food manufacturing environments.

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Biographies

Dr. Matshidiso Moso is a lecturer and researcher in the Department of Industrial Engineering at the Durban University of Technology (DUT), Faculty of Engineering and the Built Environment. She holds a Doctor of Engineering (PhD) in Industrial Engineering, a master's degree, a BTech, and a National Diploma in Industrial Engineering. She is a registered member of the Engineering Council of South Africa (ECSA) and the Southern African Institute for Industrial Engineering (SAIIE). She is committed to advancing engineering education and developing sustainable, high-performing industrial systems in South Africa and beyond. Dr. Moso has extensive industry experience in the automotive, food manufacturing, electronics, and chemical sectors, where she has applied advanced industrial engineering tools in real operational environments. Her research focuses on improving operational performance through lean manufacturing, Total Productive Maintenance (TPM), and kaizen-based continuous improvement. She integrates these approaches with sustainability and circular-economy frameworks to develop models aligned with the United Nations Sustainable Development Goals (SDGs). Her work supports organizations in improving efficiency while strengthening environmental responsibility. A key focus of her research is addressing climate change through the application of lean principles, TPM strategies, and kaizen methodologies to optimize industrial systems. Using tools such as value stream mapping, Ishikawa, 5S, and A3 problem-solving, she works to eliminate waste, improve resource utilization, and enhance operational resilience, contributing to cleaner production and reduced greenhouse gas emissions. Beyond research and teaching, Dr. Moso is dedicated to mentoring future engineers, particularly young women, and promoting international collaboration to advance sustainable, lean-based industrial innovation.

MS Okuhle Ndlovu is an Industrial Engineering student who served as the Group Leader for the Engineering Work Systems III project team(Group2). In this role, she was responsible for coordinating group activities, allocating tasks, and ensuring effective collaboration among members throughout the project lifecycle. She facilitated communication between the team and the project supervisor, monitored progress against deadlines, and guided the integration of engineering analysis with Lean Manufacturing principles. Her leadership supported the successful planning, execution, and completion of the secondary packaging optimization study and she presented the project to the industry partner.

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