



ASSESSMENT LEVEL 7

Title: Modelling & Optimisation of Automated Manufacturing Processes.

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Abstract

This study investigates simulation-driven process design and optimization for a robotic CNC machining cell producing high-performance pistons at Alpha Precision Components (APC). Starting from a Visual Components layout model with no implemented logic. A complete process flow was developed in visual components for the three-stage routing (lathe, VF-1, and five-axis finishing) and downstream manual inspection, including resource definition, control sequencing, and KPI instrumentation. Baseline simulation over an eight-hour shift showed that the initial design produced only 143 finished parts. This design also exhibited structural inefficiencies, for example, poor floor-space utilization, elongated conveyor and robot travel paths, substantial intermediate queues, and unbalanced machine and robot utilization.

Guided by lean manufacturing concepts, the robot cell was then re-engineered through three main interventions: compact layout optimization (bringing machines, buffers, and inspection closer together and reducing conveyors), redesign of robot path planning, and more precise WIP and flow rules to limit unnecessary accumulation and stabilize throughput. The optimized configuration occupies one quarter of the original footprint and, under the same processing times and shift length, increase shift output to 222 parts. This corresponds to a substantial improvement in effective throughput while reducing motion and transport waste. Comparative analysis indicates lower and more controlled WIP between operations, fewer blocking/starvation events, and more balanced utilization across the CNC machines. The tending robot, demonstrating that significant performance gains can be achieved through simulation-based redesign of layout and control without altering core machining operations.

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1 Introduction

1.1 Background

Robotic machine-tending cells are widely used to support consistent, high-rate CNC production. Their real performance depends on how well robots, machine tools, material handling, and people are integrated through layout decisions and robust control logic (Ajwad, et al., 2018). In this module assessment, the required approach is simulation-driven process design and optimization using Visual Components. An automated machine-tending operation is modelled, analysed, and improved by identifying inefficiencies through layout, utilization, process flow and applying lean and automation principles to achieve a more efficient and compliant system design. The case study focuses on Alpha Precision Components (APC), a Tier-1 supplier of high-performance pistons that has won a new contract and must ramp up production while maintaining low unit cost and high quality. There are three CNC operations in APC's proposed cell: turning on a Haas ST-30 (Op1), milling on a Haas VF-1 (Op2), and finishing on a Haas UMC-500 5-axis machine (Op3). Fanuc M-10iA/8L robots will oversee each one, and there will be conveyors and buffers between the stages and a manual inspection station at the end of the line. Initial concerns in the baseline configuration include insufficient throughput to meet demand, queue build-up between machines and a low value-adding ratio for the inspection operator. Additionally, unbalanced utilization across assets which increases the risk of late deliveries, higher operating costs, and quality issues if inspection becomes a bottleneck during commissioning.

1.2 Problem statement

APC's initial piston machining cell was developed based on shop-floor arrangement rather than a formal optimization strategy. That creates uncertainty over whether the designed system can reliably meet the new contract's required output within an 8-hour shift. Early observations show that the default setup doesn't provide enough throughput, as parts pile up in lines between operations, the manual inspection stage doesn't add much value, and robots and machine tools aren't always used equally. These problems often happen in integrated manufacturing cells where cycle times, transfer logic, and buffering decisions don't match up. This can lead to blocking or starvation and too much work-in-progress, so it might not be clear what the real limits are without structured analysis. If the cell is put into use without a redesign based on evidence, management

expects risks such as missing delivery deadlines, higher operating costs from overtime or extra shifts, and possible quality loss if inspection slows down and is rushed. There will also be less room for future growth because of the way the floor space is used. Therefore, the problem addressed in this work is to use simulation-driven analysis and experimentation to quantify baseline performance. Then identify the dominant constraints and wastes, and justify an optimized, compliant machine-tending cell design that improves flow and resource effectiveness without changing the underlying machining times.

1.3 Aim and objectives

The aim of this study is to develop and demonstrate simulation-driven process design and optimization capability by modelling an automated robotic machine-tending operation in Visual Components. Diagnosing performance losses and implementing justified improvements aligned with lean and automation principles to deliver a more efficient and compliant cell design. Using the APC piston machining case, the work focuses on recreating the baseline system and quantifying issues such as insufficient throughput, intermediate WIP, and unbalanced resource utilization. Then proposing and validating an optimized configuration using comparative simulation evidence and discussion of trade-offs, including safety, ergonomics, cost-complexity, and regulatory considerations.

Objectives:

- Conduct a critical literature review on robotics automation integration in manufacturing systems, including integration methods and relevant regulations, to inform modelling and optimization decisions.
- Develop a baseline visual components model of the APC automated machine-tending cell, defining resources and process routing.
- Collect baseline simulation data using appropriate KPIs and document key inefficiencies such as bottlenecks, blocking and motion waste.
- Validate modelling assumptions and baseline interpretation with reference to relevant academic or industrial sources.

- Design and implement optimization changes in the model grounded in lean thinking and industrial best practice.
- Run comparable baseline vs. optimized simulations and present a quantified performance comparison using Visual Components outputs, including evaluation of trade-offs for safety, cost, and compliance.

2 Literature review

2.1 Robotic machine-tending in CNC cells

Robotic machine tending has become a primary automation application in CNC machining because it enables consistent load-unload operations, higher cycle time utilization, and reduced dependence on limited skilled operators (Acentryx, 2025). Recent research on robotically automation in CNC machine tools shows that industrial and collaborative robots, along with sensors and vision systems, are now commonly used to load and unload parts and measure them while they are being worked on in lathes and machining centres (Soori, et al., 2024). This is said to improve quality and productivity, but it can be hard to make sure that the layout, safety, and control systems work together. Case studies from both academia and industry show that well-designed tending cells can increase CNC utilization from about 50–60% to 85–90%+ and boost output by more than 30–70% without adding machines (APT Manufacturing Solutions, 2021). This is mostly because they get rid of operator breaks, cut down on load-unload time, and allow for multi-machine tending strategies. At the same time, the literature emphasizes that these benefits are only realized when robot paths, part staging, and machine cycles are effectively balanced, often using simulation during the design phase to evaluate candidate configurations and avoid idle time or bottlenecks across the cell. Figure 1 shows the automated loading and unloading operation using Halter robots. All major companies use industrial robots to boost their production, especially the car manufacturing industries.



Figure 1. Automated loading and unloading of CNC machine tool (Zenoot, 2026).

2.2 Integration methodologies

In modern robotic cells, integration methodologies focus on ensuring reliable communication among robots, machine tools, conveyors and higher-level control systems. Manufacturers emphasize the necessity for standardized physical and logical interfaces among the robot controller, CNC control, and any PLC or I/O modules in robotic machine tending. To ensure that load-unload, door control, and cycle start signals are synchronized through clearly defined interaction sequences rather than custom wiring options (PROFIBUS & PROFINET International (PI), 2025). For manufacturing systems, it is suggested that frameworks like ANSI/ISA-95 be used to set up how data can be sent between shop-floor control and enterprise systems (International Society of Automation (ISA), 2026). This makes it possible for tending cells to be easily integrated into workflows for planning production, tracking it, and analysis. From a safety point of view, guidelines point directly to standards like ISO 10218-1/2, ISO 12100, ISO 13849, and ANSI/RIA R15.06. These standards require coordinated emergency stop functions, standardized safety zones, and risk assessments that look at the whole robotic application, not just the robot itself. Recent integration best-practice articles emphasize designing the control architecture so that motion

coordination and safety-related functions are distributed appropriately to manage intersecting work zones. Particularly in hybrid layouts where human operators inspect parts close to the robotized CNC cell (ISO, 2025).

2.3 Flexible manufacturing systems and buffering strategies

Flexible manufacturing systems (FMS) are usually considered as networks of machines linked by buffers (Xiaobo, Z., 2001). The amount and location of intermediate storage have a big effect on throughput, work-in-process (WIP), and how often machines get stuck or don't have enough resources. In such systems, buffers act as decoupling mechanisms by holding limited WIP between stages. They allow upstream machines to continue operating when downstream machines are temporarily unavailable. That reduces the proportion of time that resources are blocked or starved. But studies on flow lines and FMS consistently show that buffer capacity has diminishing returns. Above a certain level, larger buffers don't significantly increase throughput but do increase work-in-progress, lead time, and space needs (Amjath, et al., 2023). This means that allocating buffers must balance how responsive they are against the cost of inventory and floor space. Studies using discrete-event simulation and queueing models further demonstrate that poorly positioned or oversized buffers can hide true bottlenecks or even reduce overall performance. However, carefully located, finite buffers can stabilize flow and protect throughput under variability in processing times, failures, and arrivals. For robotic CNC cells like the APC case, this implies that the number, location, and capacity of in-line conveyors and staging positions should be designed to decouple machines just enough to avoid frequent blocking and starvation, while still supporting lean goals of low WIP and short, predictable lead times.

2.4 Lean manufacturing concepts applied to automation

Lean manufacturing for automation is a strategy to increase efficiency and reduce waste (Shah & Ward, 2007). Therefore, automated CNC cells are expected to address the classic wastes of transport, inventory, motion, waiting, overproduction, over-processing, and defects rather than simply increasing raw speed. In practice, this means designing robotic machine-tending systems so that unnecessary movements and handling steps are removed (Xia, 2024). WIP is limited to what is needed to support smooth flow, and waiting time for machines, robots, and operators is

minimised by balancing resources. Lean also emphasizes building quality into the process through concepts such as "jidoka," or "autonomation." (Tarlengco, 2025) The equipment is designed to detect abnormalities and either stop automatically or call for human intervention so that defects are contained early instead of being discovered only at end-of-line inspection.

3. Case study definition and system requirements

3.1 Company process overview

Alpha Precision Components (APC) is a Tier-1 supplier of high-performance pistons for automotive and motorsport engines. They recently secured a new contract for a turbocharged four-cylinder platform that requires a rapid increase in output while maintaining low unit cost and very high-quality levels. To support this programme, APC's engineering team has specified a dedicated three-machine CNC work cell comprising a Haas ST-30 lathe for Op1 turning of the blank piston, a Haas VF-1 vertical machining centre for Op2 milling operations, and a Haas UMC-500 five-axis machining centre for Op3 crown and skirt finishing. Each machine is operated by a Fanuc M-10iA/8L industrial robot, with inlet, transitional, and outlet conveyors allowing part delivery and buffering between operations, assisted by pallet storage and a subsequent manual inspection station. The reference process model has been created in Visual Components based on APC's existing shop-floor arrangement and is used in this study as the basis for analysing flow, resource utilisation and layout-related inefficiencies in the new piston machining operation.

3.2 Process routing and operations

The APC piston follows a fixed three-stage CNC routing followed by manual inspection, with robotic handling and conveyor buffering between each operation. In Operation 1 (Op1), Robot R1 picks a raw piston blank from the inlet conveyor (IC), loads it into the Haas ST-30 lathe, and waits for the external and internal turning cycle to complete. Then unloads the machined part to the first transitional conveyor (TC1). For Operation 2 (Op2), Robot R2 retrieves parts from TC1 and loads them into the Haas VF-1 vertical machining centre, where flats are milled and holes for features such as pin bores and oil galleries are drilled and tapped before the robot unloads them onto the second transitional conveyor (TC2). In Operation 3 (Op3), Robot R3 collects semi-finished pistons from TC2 and feeds the Haas UMC-500 five-axis machining centre, which performs crown and

skirt finishing to generate the final critical geometry. After which Robot R3 unloads the completed parts to the outlet conveyor (OC). At the end of the line, a human operator removes finished pistons from the final conveyor section, carries out manual dimensional inspection at a dedicated workbench, and then places conforming parts onto a finished-goods pallet for despatch. Figure 2 shows the factory layout of the initial design.

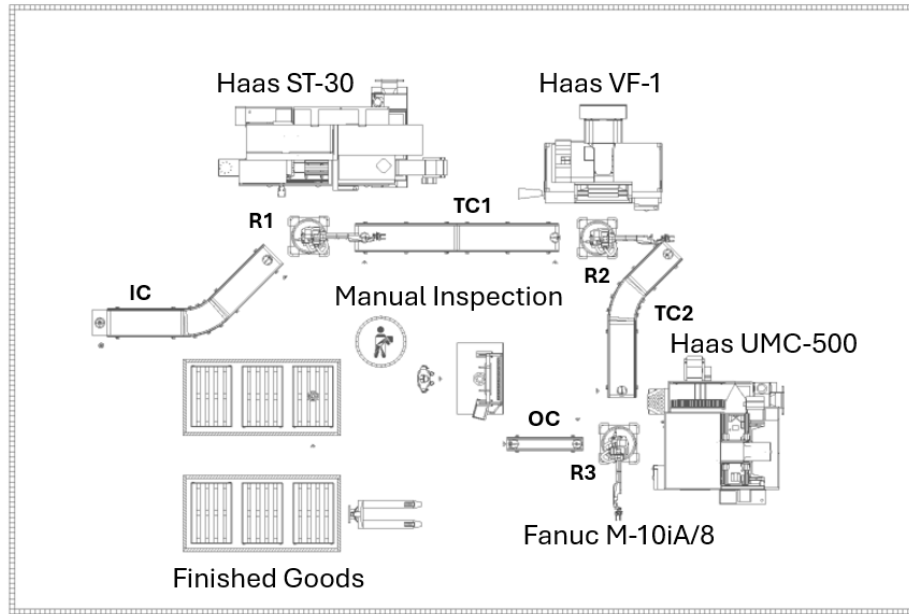


Figure 2. The initial design layout by APC engineers.

Processing Data

- Part Interarrival interval = min 200s – Max 210s
- Haas Lathe ST-30: $\mu = 3.5$ min, $\sigma = 12$ s
- Haas Vertical mill VF-1: $\mu = 2.0$ min, $\sigma = 6$ s
- Haas UMC-500 5-Axis Mill: $\mu = 4.0$ min, $\sigma = 18$ s
- Full inspection: $\mu = 2.5$ min, $\sigma = 30$ s
- Robot Joint Speeds = 50%
- Conveyor Speeds = 500 mm/s
- Walking Speed = 1200 mm/s (Unloaded) 1000 (Loaded)
- Shift Length = 8 hours

The given processing data is based on the initial design. These values will be same for the optimized design as well. The key objective is to change the layout of the design and obtain a better throughput result.

4. Development of Visual Components Model

4.1 Modelling approach

In this study, the starting point was a Visual Components model that represented only the physical layout of the APC piston machining cell. The provided file does not contain any implemented process logic or performance instrumentation. The first stage of the work therefore involved developing a process map and control sequence for the complete routing: Op1 lathe → Op2 VF-1 → Op3 5-axis → manual inspection → stock them in pallets. After that, it is required to configure and connect all resources in the simulation environment, including robots, CNC machines, conveyors, and the inspection operator. Figure 1Figure 3 shows the primary physical layout designed by the APC engineers.

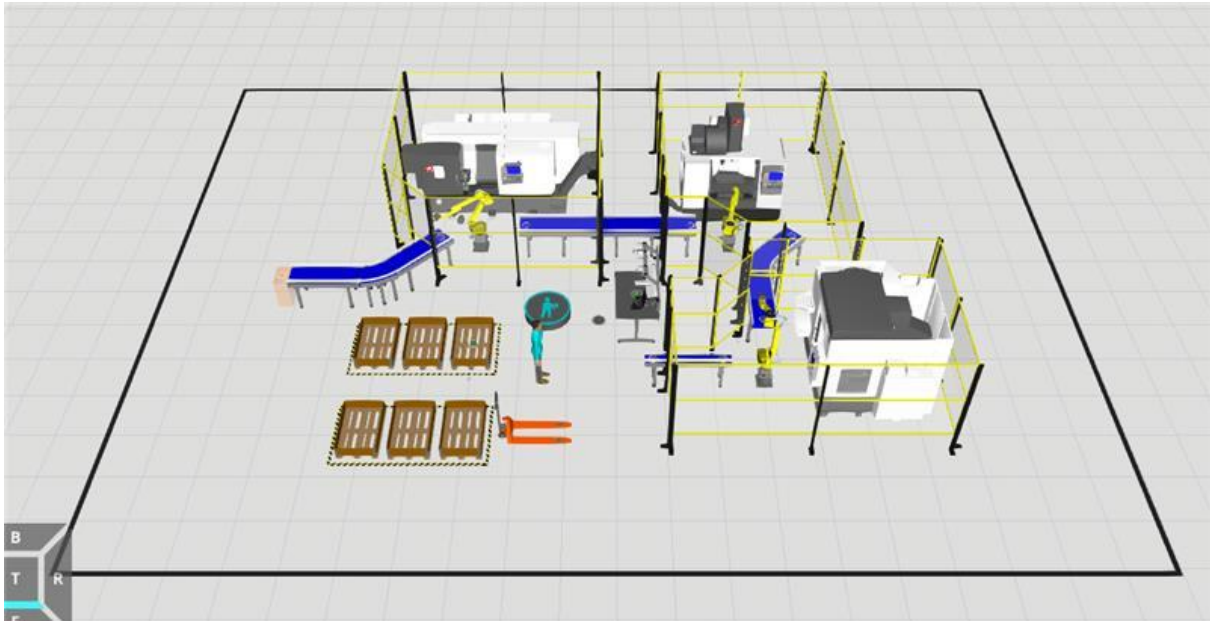


Figure 3. Initial physical layout of the model.

In the process sequence on the next page, the short form is referred to as,

IC = inlet conveyor, TC = transitional conveyor, OC = outlet conveyor

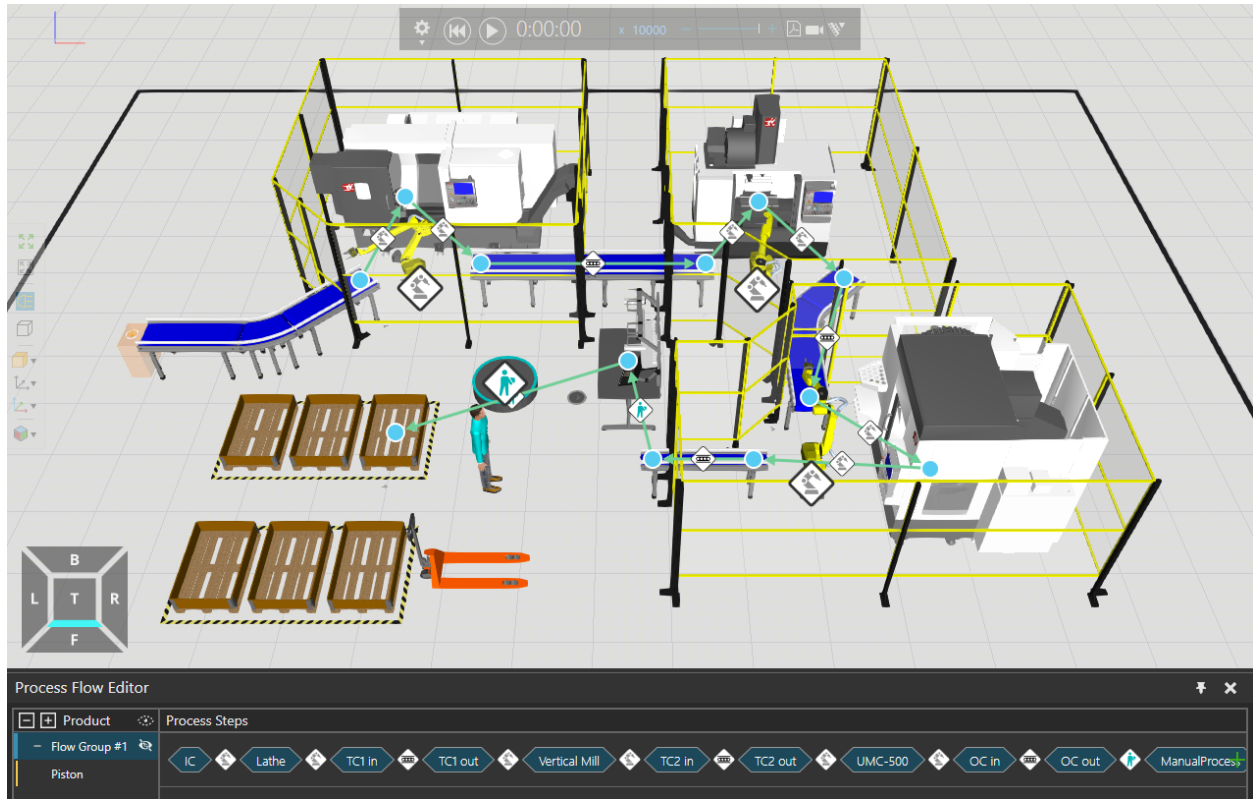


Figure 4. Process steps for the APC engineer's design.

Figure 4 contains the process steps for the APC engineer's design. The steps are as follows.

IC→Lathe→TC1 in→TC1 out→Vertical mill→TC2 in→ TC2 out →UMC-500→OC in→ OC out→Manual process→to Pallet.

4.2 Fundamental efficiency of the initial design

After completing the process flow, the baseline Visual Components model of the APC piston machining cell was simulated for a single 8-hour production shift. The processing time for all the machines, conveyor speed and human working speed is taken from the process data from 3.2. Under these conditions, the system produced 143 finished pistons, corresponding to an average throughput of approximately 17.9~18 parts/hour. Figure 5 shows the result from visual components after an 8-hour shift.

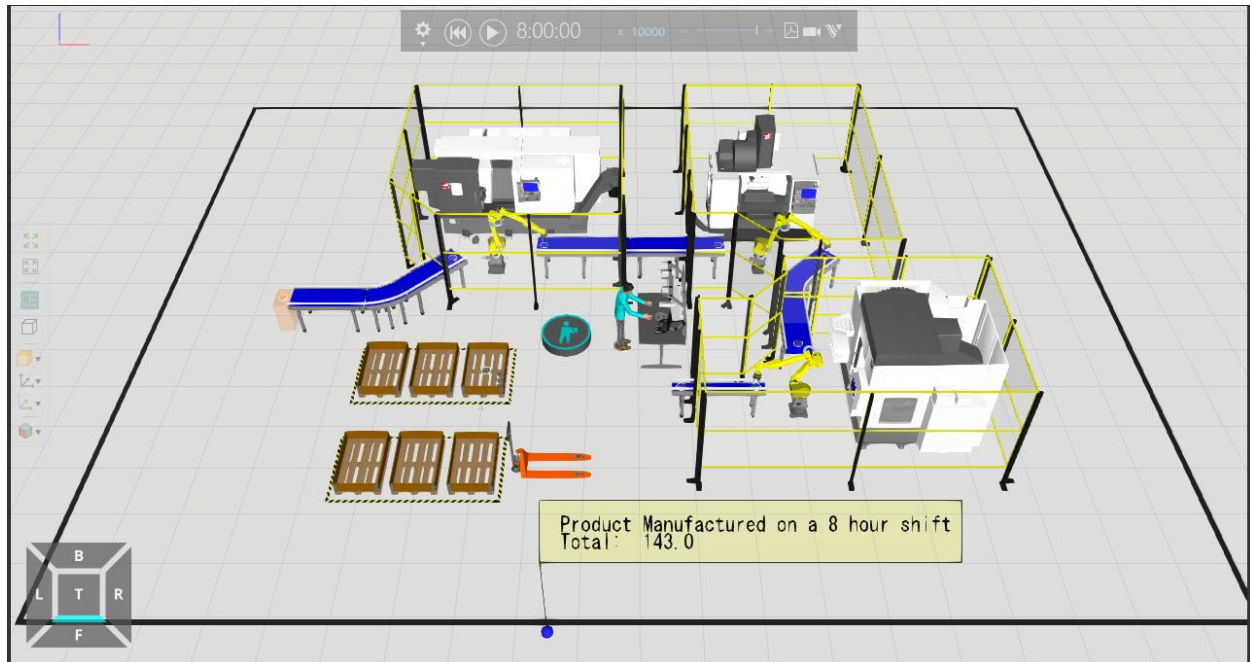


Figure 5. Base model simulation result for an 8-hour shift.

5. Design Optimization

5.1 Optimisation goals and success criteria

The optimisation work in this study focuses on improving the overall flow efficiency, resource utilisation, and functionality of the APC piston machining cell, rather than meeting a pre-specified numerical production target. The primary goal is to redesign the layout to ensure the cell delivers higher and more stable throughput, with reduced intermediate queues and motion waste. The process data is kept as default.

This involves simplifying the physical arrangement by removing unnecessary items. As well as shortening transport distances and improving part staging so that robots and the inspection operator can perform their tasks with fewer non-value-adding movements and less walking. The key factor is to increase the number of products manufactured within an 8-hour shift to be greater than the primary design.

5.2 Selected changes

The key problems with the initial design include the floor space utilization, unnecessary equipment that creates bottlenecks and extra processing time. In the new layout, the equipment is brought together to reduce the travel time for the workpiece. The number of conveyor belts has been reduced. The workpiece path is kept linear for the robot to work efficiently and avoid a curved path. Instead of three individual robots, one robot is used to handle the workpiece loading and unloading. This not only reduced the manufacturing cost but also decreased the throughput time. Figure 6 shows the top view of the new layout. The feeder time interval was reduced to 120s instead of 200s.

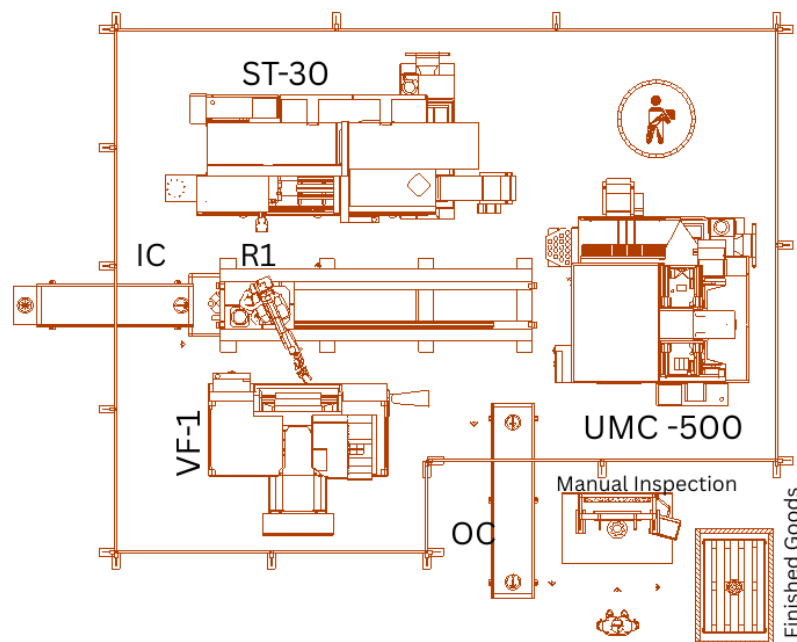


Figure 6. Top view of the new layout.

From a lean perspective, the selected changes aim to eliminate motion and transport waste by shortening the paths travelled by parts, robots, and the operator. This also simplifies material flow. So that route is more linear and easier to control. Nonessential layout elements, for example, excessively long conveyor segments, unnecessary gaps between workstations, or staging locations that did not contribute to flow, were removed. That also supports better space utilization and future expandability of the cell.

5.2.1 Layout optimisation

In the baseline arrangement, the three CNC machines, their associated robots, and multiple conveyor segments were distributed over a relatively large footprint. This resulted in prolonged part-transfer distances, curved robot paths, and additional handling stages that contributed to motion and transport waste. Certain conveyor sections and staging points did not add functional value to the process but still introduced extra transfer time and potential blocking points, thereby increasing overall throughput time and complicating material flow control.

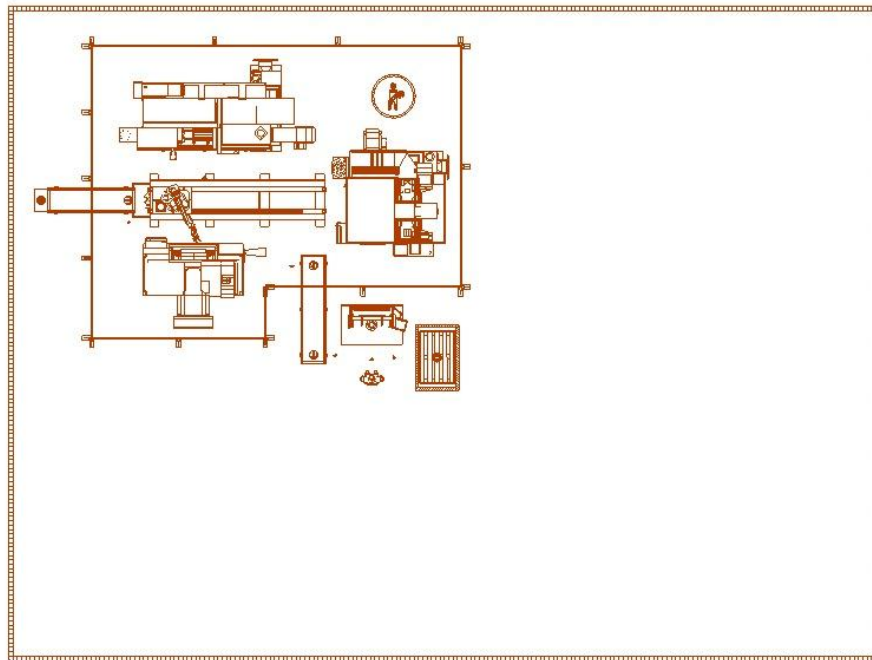


Figure 7. 2D view of the new layout including floor space.

Figure 7 shows the optimized layout, the core resources were brought closer together and aligned to create a more compact, linear process flow for the workpiece. The routing of the workpiece was deliberately kept as straight as possible so that the tending robot can operate along a predominantly linear path. From a lean perspective, these layout changes are intended to remove non-value-adding movement of parts and resources, simplify flow paths, and improve space utilization.

5.2.2 Robot path planning

Alongside the physical rearrangement of equipment, the robot motion strategy was redesigned so that the single tending robot could service all three CNC machines using shorter, more repeatable paths. In the initial configuration, each machine had its own dedicated robot, and the combination of separated machine locations and multiple conveyor sections led to relatively long and curved robot trajectories when approaching or leaving machine doors and conveyors. These factors increased handling time per part and contributed to motion waste, even though the underlying machining times remained unchanged.

A robot floor track was used where one single robot was able to move freely on its track. The robot has access to all the machines and conveyors. Overall, the revised path planning supports the lean objective of eliminating unnecessary motion while ensuring that robot trajectories remain collision-free and compatible with the tightened layout and safety requirements.

5.2.3 Buffer and flow rules

Given the reduced number of conveyors and staging locations in the optimized layout, it was necessary to redefine buffer capacities and flow rules to prevent both excessive WIP and new forms of blocking or starvation. In the baseline configuration, multiple conveyor segments effectively acted as large, loosely controlled buffers between operations, allowing parts to accumulate and obscuring where the true bottlenecks were located, while also increasing average lead time. The innovative design introduces tighter limits on the number of parts permitted between Op1–Op2 and Op2–Op3 so that only a small, controlled queue is maintained ahead of each downstream machine.

Figure 8 contains the process steps for the optimize design. The number of steps has reduced significantly. The steps are as follows.

IC→Lathe→Vertical mill→UMC-500→OC1 in→ OC1 out→Manual process→to Pallet.

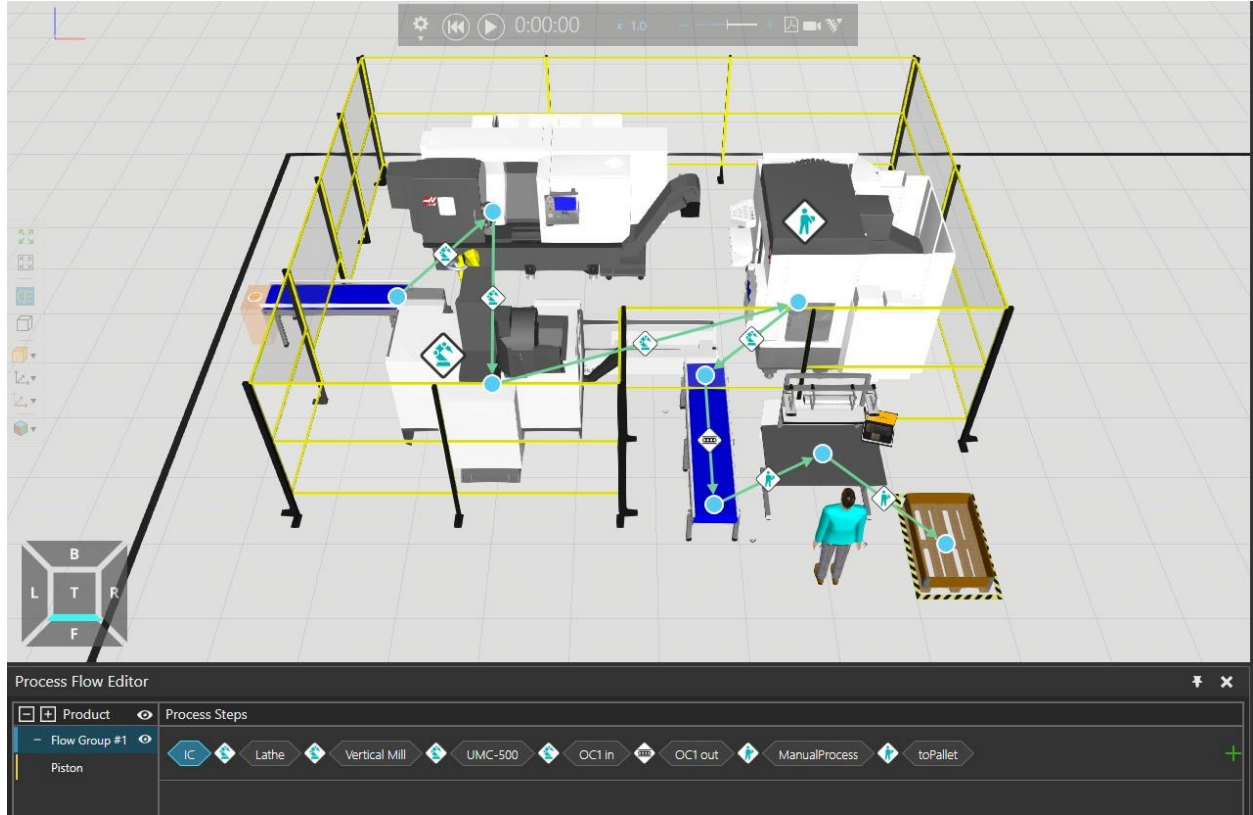


Figure 8. Process flow of the new model.

Process flow was adjusted so that the robot only transfers a part into a buffer if there is confirmed capacity downstream, rather than continuously pushing parts forward regardless of the state of the next machine. This rule helps to reduce blocking at machine exits and avoids flooding intermediate buffers when the downstream resource is temporarily busy or waiting on inspection capacity.

6. Results and comparative analysis

The baseline implementation of the APC piston machining cell produced 143 finished parts during an 8-hour simulated shift. On the other hand, the optimized configuration achieved 222 parts (Figure 9) over the same period, representing a substantial increase in effective throughput without any reduction in machining times. This improvement arises from the combined effect of the compact layout, simplified robot path planning, and simpler flow rules. Combining together reduces non-value-adding transfer time and makes resource usage more balanced across the cell.

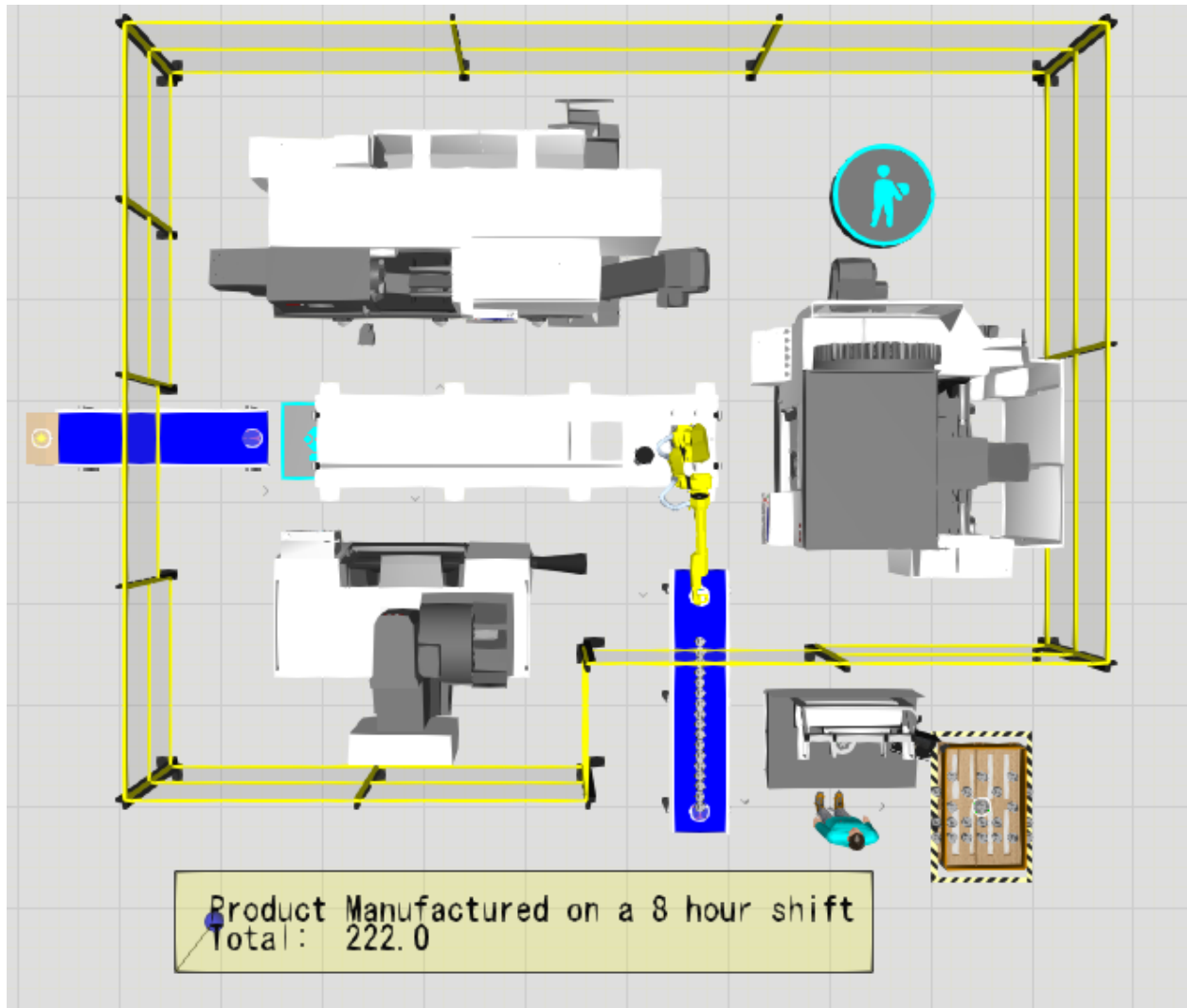


Figure 9. Optimized model Simulation.

Table 1. Result comparison between initial and optimized model.

8-hour shift	APC Layout	Optimized Layout
Parts produced	143	222
Average throughput (parts/hour)	17.9	27.8
Number of process flow	12	8
Number of Robots	3	1
Qualitative WIP	Higher	Lower
Robot Utilization	Less Balanced	More Balanced

In comparison with the baseline model, queues built up between CNC operations and at the inspection stage, while at least one machine and its tending robot experienced frequent idle periods due to blocking or starvation. By confirming that the initial floor-space utilization and material-handling design created structural inefficiencies. Under the optimized design, average WIP levels between operations are lower and more stable, with shorter and better-controlled queues; idle periods for the CNC machines and the single tending robot are reduced, and the manual inspection activity is less affected by large, intermittent surges of parts. The more linear workpiece path and reduced conveyor count also decrease the total distance travelled by parts and the operator, supporting lean objectives of eliminating motion and transport waste while improving space utilization.

7. Conclusions

The simulation study has demonstrated that systematic redesign of layout, robot utilization, and flow control can significantly improve the performance of the APC piston machining cell without altering the underlying machining processes. By transforming the layout into a more compact, linear configuration, consolidating workpiece handling into a single tending robot, and introducing tighter WIP rules, the optimized model increased 8-hour shift output from 143 to 222 finished parts. At the same time, reducing unnecessary transfer movements and intermediate queues. These results indicate that the initial design's low throughput and unbalanced utilization were primarily driven by floor-space usage, conveyor configuration rather than by machine cycle times themselves.

This work demonstrates how lean manufacturing principles, particularly the minimization of motion and transport waste. The design of robotic CNC cells can incorporate improved WIP management and more efficient material flow through the application of simulation-based methods. Visual Components offered a practical setting to execute and evaluate different configurations, measure their effects utilizing relevant KPIs, and investigate trade-offs among throughput, space usage, and resource allocation prior to any physical modifications on the shop floor.

8. Future work

Future work includes testing multiple combinations of layout configurations to identify the most efficient arrangement for the robotic CNC cell. This could involve systematically varying machine order, cell shape, spacing between resources, and the positioning of buffers and inspection relative to the main material flow, with each configuration evaluated in simulation against throughput, WIP, and utilization parameters.

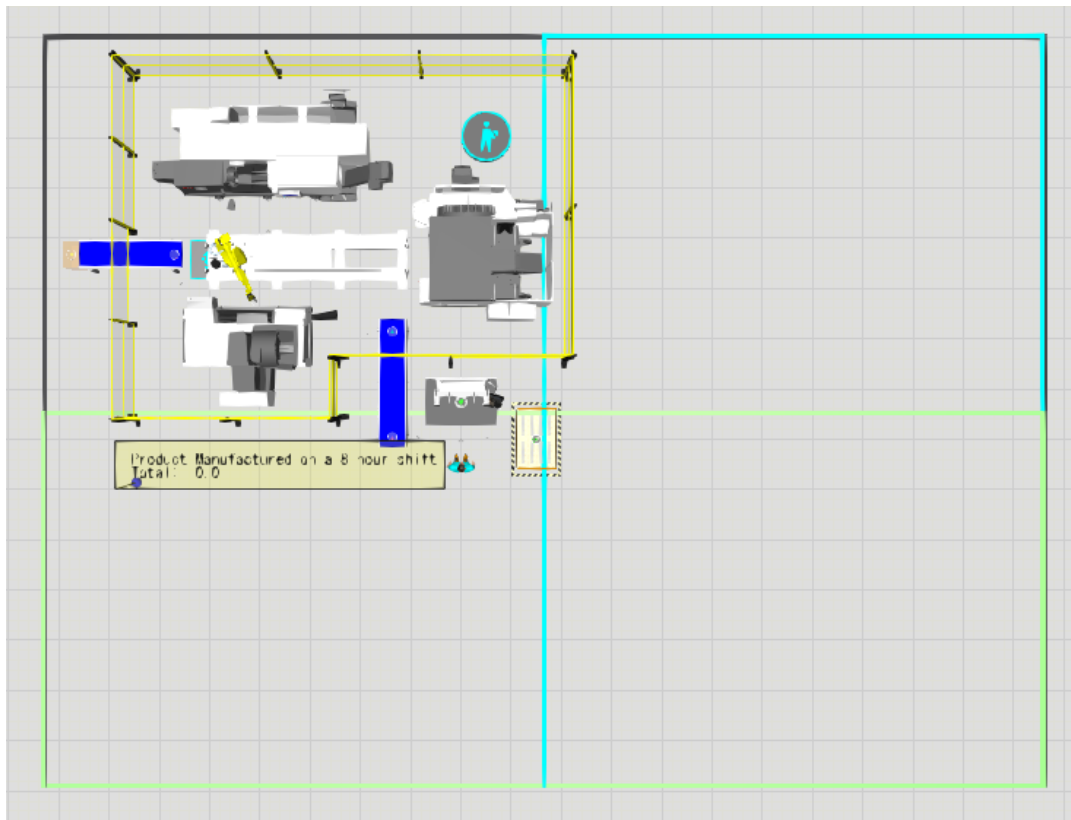


Figure 10. Floor space comparison.

A different approach involves eliminating the manual inspection step and fully automating the entire procedure, in order allowing continuous operation of the production process for 24 hours. The present optimal layout occupies approximately one-quarter (Figure 10) of the floor space. This implies that by replicating the same configuration, the production capacity may quadruple. This would enable the organization to process a greater volume of orders.

References

Acentryx, 2025. *Robotic Machine Tending: Automating Loading and Unloading with Precision*. [Online]

Available at: <https://acentryx.com/machine-tending>

[Accessed 07 February 2026].

Ajwad, S. et al., 2018. Optimal and robust control of multi DOF robotic manipulator: Design and hardware realization. *Cybernetics and Systems*, 49(1), pp. 77-93.

Amjath, M., Kerbach, L., J.M., S. & Elomri, A., 2023. Optimisation of Buffer Allocations in Manufacturing Systems: A Study on Intra and Outbound Logistics Systems Using Finite Queueing Networks. *Applied Sciences*, 12(17).

APT Manufacturing Solutions, 2021. *Association for Advancing Automation (A3)*. [Online]

Available at: <https://www.automate.org/robotics/case-studies/cnc-machine-tending-with-fanuc-robodrill>

[Accessed 07 February 2026].

International Society of Automation (ISA), 2026. *ISA-95 Standard: Enterprise-Control System Integration*. [Online]

Available at: <https://www.isa.org/standards-and-publications/isa-standards/isa-95-standard>

[Accessed 07 February 2026].

ISO, 2025. *ISO 16843-2:2025 — Health informatics: Categorical structures for representation of acupuncture*. [Online]

Available at: <https://www.iso.org/obp/ui/en/#iso:std:iso:16843:-2:ed-1:v1:en>

[Accessed 07 February 2026].

PROFIBUS & PROFINET International (PI), 2025. *PROFIBUS & PROFINET International*. [Online]

Available at: <https://www.profibus.com/technologies/robotics-srci-standard-robot-command-interface>

[Accessed 07 February 2026].

Shah, R. & Ward, P., 2007. Defining and developing measures of lean production. *Journal of Operations Management*, 25(4), p. 785–805.

Soori, M., Karimi Ghaleh Jough, F., Dastres, R. & Arezoo, B., 2024. Robotical Automation in CNC Machine Tools: A Review. *Acta Mechanica et Automatica*, Volume 18, pp. 434-450.

Tarlengco, J., 2025. *Understanding Jidoka: A Lean Principle in Manufacturing*. [Online]
Available at: <https://safetyculture.com/topics/jidoka>
[Accessed 10 February 2026].

Xiaobo, Z., 2001. Allocation of Buffer Spaces in a Flexible Manufacturing System: A Model and a Case Example. *The Journal of the Operational Research Society*, 52(12), pp. 1350-1358.

Xia, S., 2024. *Lean Manufacturing Guideline Principles and Waste Types*. [Online]
Available at: <https://bccncmilling.com/lean-manufacturing-guideline-principles-and-waste-types/>
[Accessed 10 February 2026].

Zenoot, 2026. *Case study: Lathe tending system modified to extend unattended production*. [Online]
Available at: <https://zenoot.com/articles/case-study-lathe-tending-system-modified-to-extend-unattended-production>
[Accessed 07 February 2026].