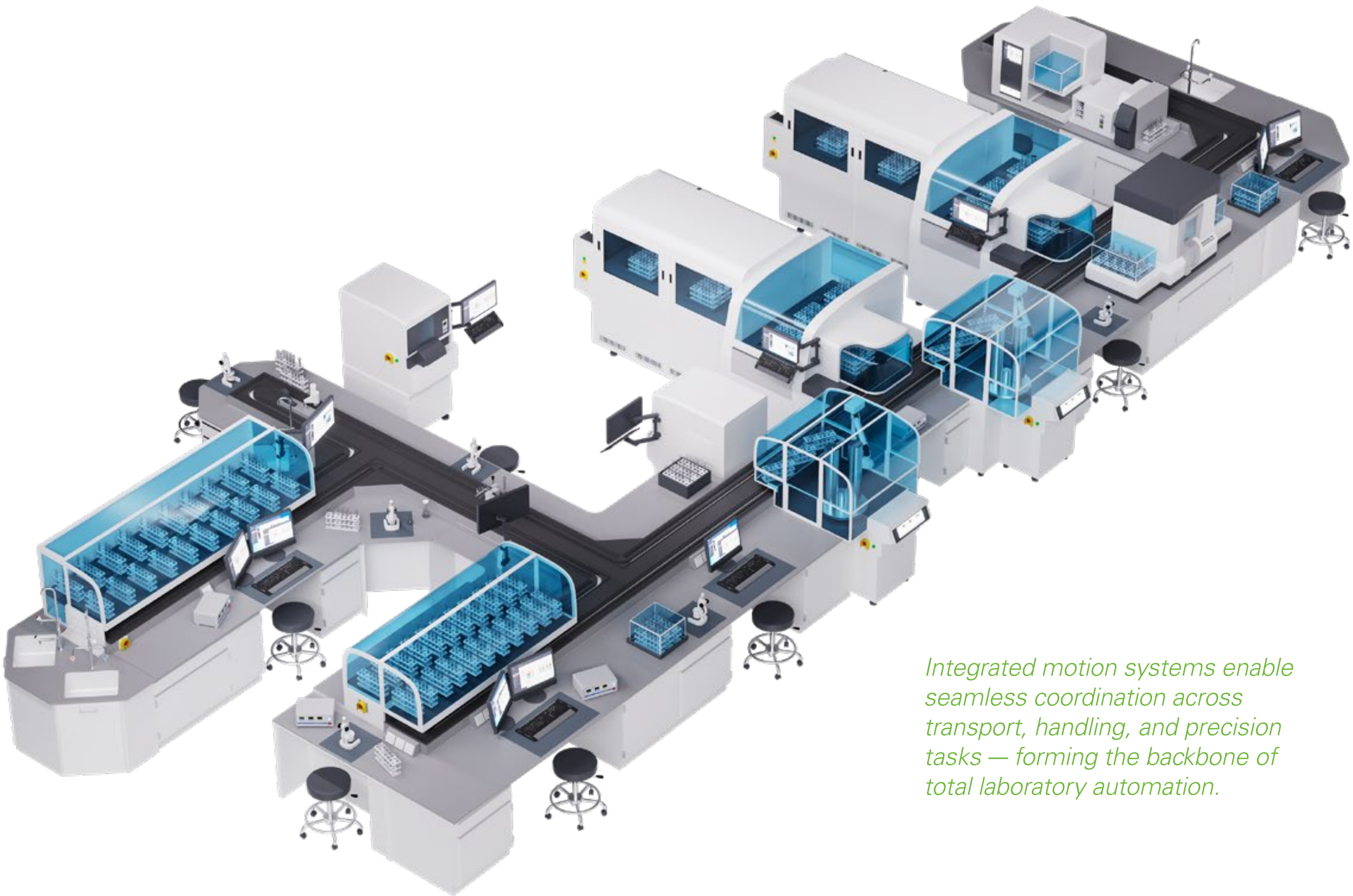
WHITE PAPER

Beyond Throughput: Why Motion Architecture Determines the Success of Total Laboratory Automation

Motion is the foundational element that enables Total Laboratory Automation (TLA) systems to function as cohesive, high-efficiency diagnostic workflows. While discussions of TLA often emphasize informatics, connectivity, and analytics, it is the physical movement of specimens, carriers, and mechanical components that ultimately determines throughput, bottleneck behavior, and operational reliability.

In fully automated environments, every stage of the workflow — pre-analytical, analytical, and post-analytical — depends on coordinated motion to maintain continuity. Transport systems, robotic handling, and precision positioning must all operate in synchrony, translating digital workflow logic into physical execution. As a result, motion cannot be treated as an isolated subsystem; it is the mechanism through which the entire automation strategy is realized.

Motion in TLA extends beyond simple conveyance. It includes track-based transport, robotic manipulation, and precision micromotion tasks such as gripping, capping, de-capping, and pipetting. It also encompasses dynamic routing, where samples are prioritized and redirected in real time based on workflow conditions. Designing systems that can manage this combination of speed, precision, and adaptability is central to achieving scalable and reliable automation.



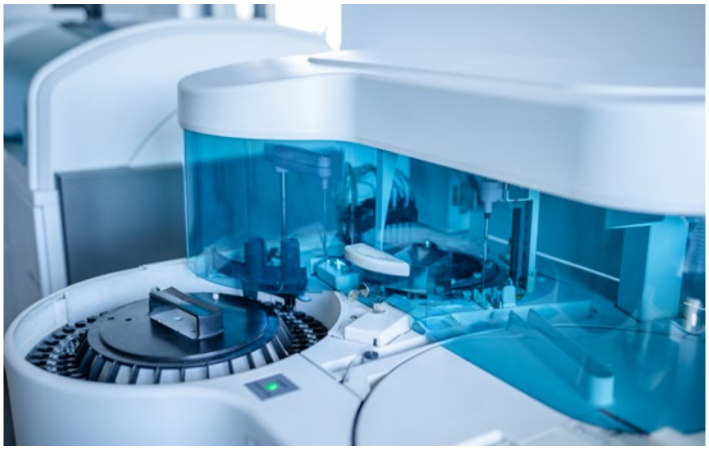
Integrated motion systems enable seamless coordination across transport, handling, and precision tasks — forming the backbone of total laboratory automation.

Pre-Analytical Complexity and the Demands on Motion Systems

The pre-analytical phase contains the highest concentration of discrete interactions with samples, making it the most motion-intensive portion of the workflow. From the moment racks of tubes are introduced into the system, motion begins to dictate both efficiency and accuracy. Samples must be routed through identification, sorting, centrifugation, and preparation steps, each requiring coordinated transport and handling.

This phase highlights one of the fundamental challenges in TLA design: balancing throughput with gentle handling. Motion systems must operate at speeds that support high-volume processing, while avoiding conditions that could lead to hemolysis, tube collisions, or barcode misreads. Achieving this balance depends on the use of controlled motion technologies — such as servo and brushless DC motors — combined with feedback systems that ensure precise positioning under varying load conditions.

At the same time, routing is rarely static. Workflow priorities such as STAT processing introduce variability, requiring motion systems to dynamically adjust speed, sequencing, and coordination. What appears to be a simple conveyance task becomes a continuously adapting process, where consistency must be maintained despite changing inputs.



High-throughput sample intake relies on controlled, coordinated motion to balance processing speed with gentle handling and accuracy.

Automated sorters further increase the demands on motion precision. Rapid pick-and-place operations determine the downstream path of each sample, and even minor deviations in timing or placement can introduce errors that propagate through the system. Because these errors often manifest later in the process, they can be difficult to attribute to their source, reinforcing the importance of stability and repeatability at this early stage.

The pre-analytical environment, with its combination of rotational and linear motion requirements across a wide range of speeds and forces, requires a system-level approach to design. Components selected for individual performance must ultimately function as part of a coordinated whole, capable of maintaining accuracy under real-world variability rather than idealized conditions.

Analytical Phase Synchronization and System Throughput

As samples enter the analytical phase, system performance becomes a function of synchronization rather than discrete handling. Motion architecture governs how effectively samples are delivered to analyzers in a continuous, coordinated flow, aligning transport timing with instrument availability and cycle states.

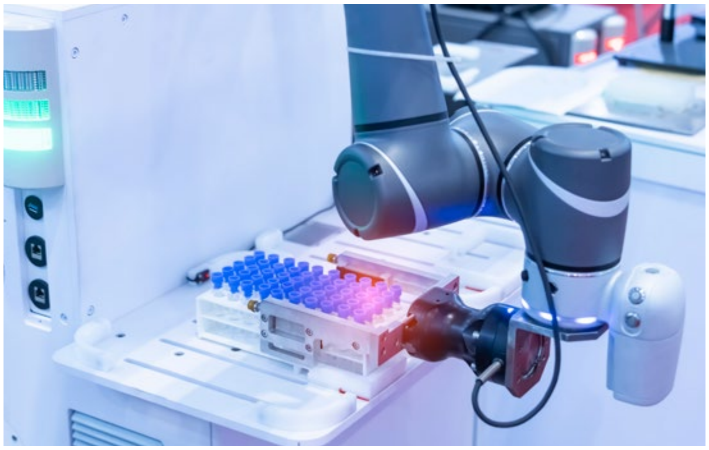
This synchronization requires tightly controlled motion profiles — enabled by servo and brushless DC systems, encoder feedback, and closed-loop control — to ensure samples arrive with both the correct timing and positional stability. Small deviations in motion profiles or alignment can introduce vibration and placement error, disrupting analyzer cycles and reducing effective throughput.

At the point of interaction, motion precision becomes even more critical. Sample probes, reagent rotors, and pipetting modules rely on deterministic positioning and repeatable timing. Motion is therefore not just transporting samples, but conditioning how they are presented to the analyzer. Instability at this interface can lead to missed reads, extended cycle times, and reduced analyzer efficiency.

Attempts to increase throughput by simply increasing transport speed often expose these constraints. Higher velocities may improve transit time, but can degrade positioning accuracy and settling behavior at the moment of analysis. Sustained performance instead depends on coordinated motion control strategies rather than incremental speed increases.

Analytical workflows must also accommodate variability, including flagged samples and exception handling. Supporting these conditions requires motion systems capable of dynamic, bi-directional routing with real-time feedback, allowing the system to maintain flow without introducing instability.

Systems designed around fixed, linear transport models often struggle in this environment. When motion lacks adaptability, exception handling introduces friction — manifesting as localized queuing, missed timing windows, and reduced analyzer utilization. In contrast, architectures built on closed-loop motion control can continuously adjust behavior based on system feedback, maintaining performance as conditions change.



Precise motion synchronization ensures accurate sample positioning and consistent analyzer performance under continuous system demand.

In this phase, throughput is not defined by how fast samples move, but by how precisely motion systems synchronize transport, positioning, and analyzer interaction under variable operating conditions.

Post-Analytical Handling and the Importance of Precision

Following analysis, motion continues to play a critical role in ensuring traceability, storage integrity, and controlled disposal. While the post-analytical phase is less visibly dynamic, it places greater demands on precision and long-term reliability — where motion architecture directly differentiates system performance.

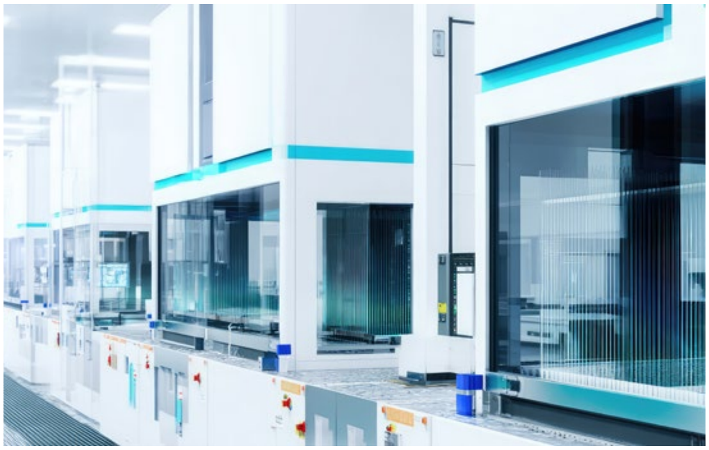
Automated storage requires coordinated multi-axis motion — combining vertical lifts, horizontal transport, and retrieval mechanisms — to operate within increasingly dense environments. As storage density increases, tolerance windows narrow, and even small positioning errors can result in misplacement or failed retrievals. Maintaining accuracy at scale depends on closed-loop motion control and consistent positioning across high cycle counts.

Traceability depends on precise barcode alignment, often requiring controlled rotational positioning. Even small inconsistencies can lead to misreads, requiring manual intervention and impacting operational efficiency.

Unlike earlier stages, where errors may be detected quickly, post-analytical issues often surface only during retrieval. This delayed visibility increases the importance of repeatability and long-term accuracy, particularly in high-cycle systems. Motion must maintain consistent performance over time despite wear, load variation, and continuous operation.

Controlled disposal further extends motion requirements, ensuring samples are removed safely and predictably without disrupting overall system flow.

In this phase, differentiation is not driven by speed, but by how reliably motion systems maintain precision, alignment, and repeatability under high-density, high-cycle conditions.



High-density storage and retrieval systems depend on repeatable, multi-axis motion to maintain traceability and long-term reliability.

Safety, Coordination, and Human Interaction

Across all phases of TLA, motion systems must operate within strict safety constraints. Sensors for spill detection, misload detection, and obstruction monitoring, along with interlocks that prevent access to moving components, are critical to protecting both personnel and equipment.

As system speeds increase in pursuit of higher throughput, the relationship between performance and safety becomes more complex. Faster motion amplifies the consequences of errors, requiring greater predictability and tighter control. Designing systems that maintain both efficiency and safety demands early integration of these considerations, rather than treating them as secondary requirements.

Human interaction adds another layer of complexity. In environments where operators and automated systems coexist, motion must be not only precise but also predictable. Collaborative scenarios require coordinated behavior that minimizes risk while maintaining productivity, presenting a significant design challenge for engineering teams.

Motion Architecture and System Performance at Scale

Motion architecture ultimately determines how TLA systems perform beyond ideal conditions — and serves as a primary design lever for engineers to control throughput, reliability, and overall system behavior. While systems may validate successfully, real-world operation introduces variability and sustained demand, exposing limitations rooted in how motion is designed and coordinated.

Small mismatches in timing and positioning can cascade across the system, creating inefficiencies that standard specifications often fail to capture. Over time, high-cycle operation further amplifies these effects through wear and performance drift, making long-term stability a critical design consideration.

In this context, motion is not simply a mechanical layer — it is the framework that governs how TLA systems operate at scale. Systems that prioritize coordinated, closed-loop motion are better equipped to maintain consistent performance, while those that do not are more likely to encounter bottlenecks as they grow.

As automation continues to advance, the ability to sustain performance under real conditions will define success. Motion architecture is the factor that ultimately determines whether those outcomes are achieved.

Dave Beckstoffer
Senior Industry Manager
Portescap

About the Company

At Regal Rexnord, we create a better tomorrow with sustainable solutions that power, transmit, and control motion. Focused on customer needs and committed to sustainability, we harness innovation to transform industries and create a brighter future. From high-performance, precision motion control systems that power surgical robots, humanoids, satellites, and unmanned aerial vehicles, to advanced automation systems that optimize motion across factory floors, to precision-engineered power transmission components and innovative air moving solutions that drive efficiency, our technologies fuel progress.

The impact of Regal Rexnord's innovation capability goes far beyond our expertise and resources in surgical robotics. For more than 125 years, our portfolio of technology brands has grown intentionally and thoughtfully. We find the best and brightest ideas, bring them together under a single roof, build them to suit each customer's purpose, and create value far beyond their individual potential.

Utilizing our deep knowledge of the unique motion needs of the industries we serve -- robotics, aerospace, space, defense, medical, data centers, factory automation, renewable energy, agriculture, construction, and more -- we collaborate with our customers and serve as trusted advisors to deliver optimized solutions. Customer-focused innovation drives us, and our global network of design and manufacturing centers enables us to effectively engineer and reliably produce the complex solutions required to drive progress all around the world.

Headquartered in Milwaukee, Wisconsin, and with a worldwide presence of over 200 locations and 30,000 associated dedicated to customer success, Regal Rexnord (NYSE: RRX) empowers global industries to thrive sustainably while Creating a Better Tomorrow.

Portescap KOLLMORGEN REXNORD™
THOMSON® WARNER ELECTRIC™

Regal Rexnord
110 Westtown Road
West Chester, PA 19382 - USA
+1 610-235-5499 | portescap.sales.america@regalrexnord.com
portescap.com | regalrexnord.com

The proper selection and application of products and components, including assuring that the product is safe for its intended use, are the responsibility of the customer. To view our Application Considerations, please visit https://www.regalrexnord.com/Application-Considerations.
To view our Standard Terms and Conditions of Sale, please visit https://www.regalrexnord.com/Terms-and-Conditions-of-Sale

"Regal Rexnord" is not indicative of legal entity. Refer to product purchase documentation for the applicable legal entity.
Regal Rexnord, Kollmorgen, Portescap, Rexnord, Thomson, and Warner Electric are trademarks of Regal Rexnord Corporation or one of its affiliated companies.
© 2026 Regal Rexnord Corporation, All Rights Reserved. MCWP-13042-C-EN-US 07/26

RegalRexnord™