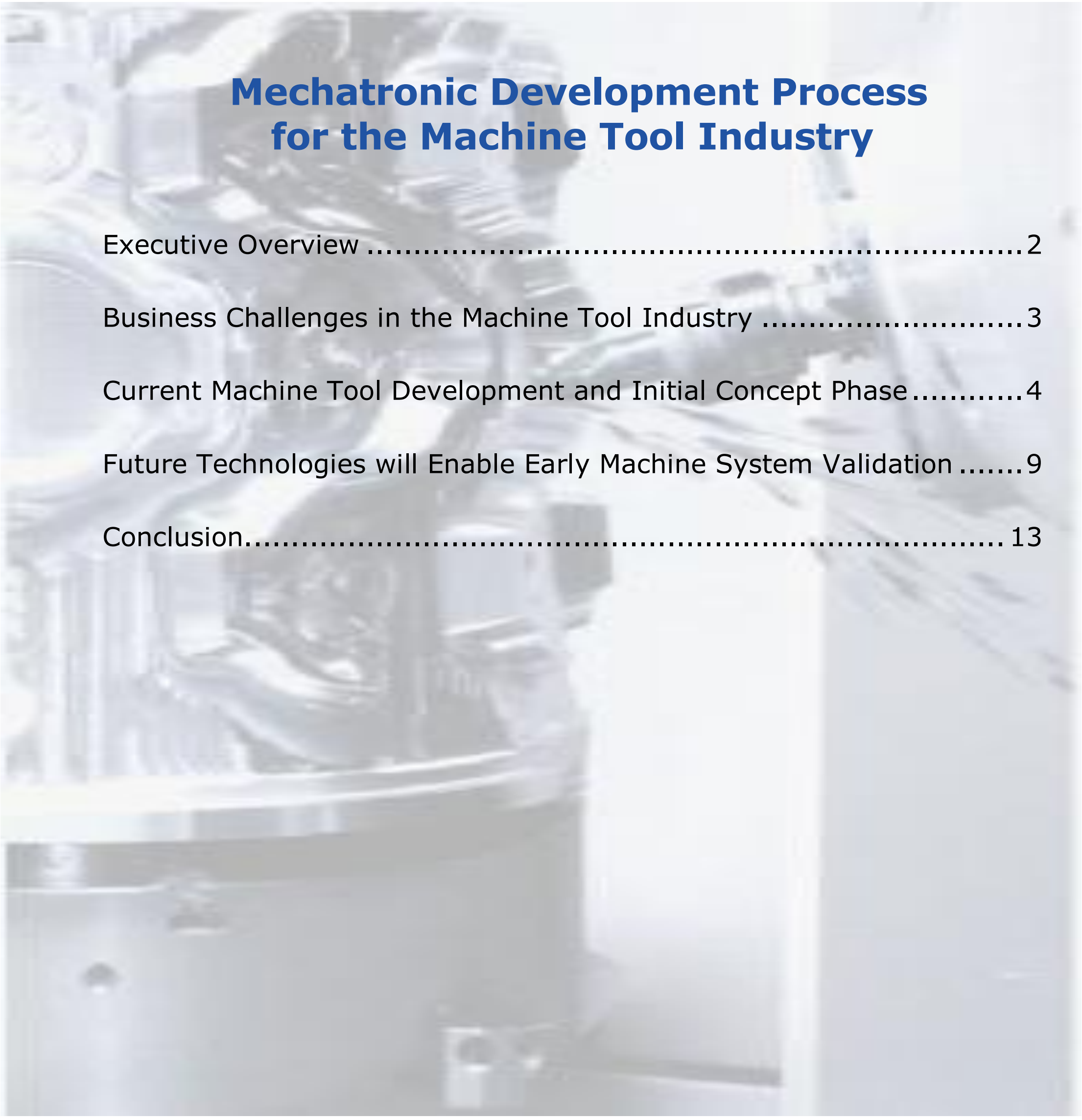
ARC WHITE PAPER

By ARC Advisory Group

SEPTEMBER 2010



Mechatronic Development Process for the Machine Tool Industry

Executive Overview

Since the recent economic downturn hit the discrete manufacturing industries particularly hard, the OEM machine tool builders that serve these industries are under enormous pressure. In today's risk-averse, tight capital environment, end user manufacturers only purchase new equipment when they can no longer effectively redeploy existing equipment. A whole new business environment in which manufacturing end users delay capital equipment purchases until the last possible moment is underway.

Machine tool executives are identifying opportunities in their organization to streamline both new product development and the final assembly of machinery to improve delivery cycles. The complexity of integrating mechanical, electrical, automation software and other subsystems often impedes time to market. The business imperative is to adopt more efficient internal development practices that encompass conceptual design through detailed design and delivery.

The complexity of integrating mechanical, electrical, software and other subsystems requires clear definition of functional requirements early in the concept design phase.

Typically, OEMs move directly from customer requirements to the detailed engineering design phase, without developing a functional model of the complete machine system. During the critical concept development phase e, in which designers map customer requirements into functional specifications, the project length and complexity can be mitigated by developing and decomposing a model of the complete machine system functions. The capability to evaluate alternatives much earlier in the design cycle leads to innovative solutions that meet performance and cost objectives, as well as streamlining the entire development process.

Adopting development methods that facilitate a "mechatronic," systems engineering approach early in the design process is required. Development methods that enable close cooperation between the different engineering disciplines increase the efficiency of engineering resources. The emergence of integrated design tools that support functional modeling based on an interdisciplinary systems engineering design approach enhances the ability of machine tool OEMs to meet time-to-market and system complexity challenges while ensuring the final system meets the customer requirements and expectations.

Business Challenges in the Machine Tool Industry

The recession that began in 2008 significantly impacts the way today's manufacturers conduct business. Pressure points for machine tool builders of standard machines and custom engineered machines are mounting as past business models no longer match current economic realities.

Delivery Times Become Shorter

In the current economic climate manufacturers now retain capital resources as long as possible. Before committing to capital expenditures in machinery, purchases are often delayed until the last possible moment as existing equipment is evaluated for redeployment. The result is that machine tool buyers are now expecting very rapid delivery times.

> In the current economic climate where capital purchases are often delayed until the last possible moment, machine tool buyers demand and expect very rapid delivery times.

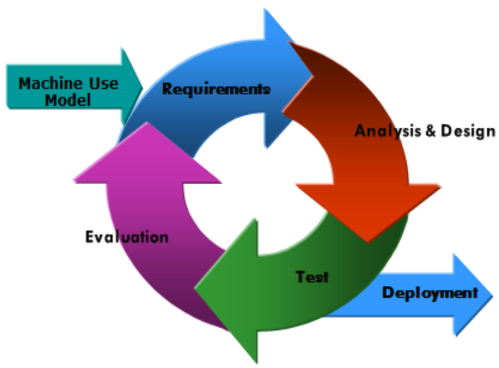
Machine tool builders have historically stocked inventory in the sales channel for standard machine tools. However, stocking inventory with standard machine tools negatively impacts cash flow while also being financially risky as the overall demand is uncertain. Similarly, delivery times for custom engineered or standard machines that require adaptations have been significantly shortened. These factors are driving executives to seek efficient business models that facilitate "Just In Time" delivery for both standard and custom engineered machinery.

Manufacturers Strain Engineering Organizations

Manufacturers scaled down their engineering work forces throughout this recession. The downsizing of this skilled talent pool in manufacturing organizations is placing a strain on machine tool builders engineering organizations. In addition to providing machinery, machine tool builders are functioning as an extension of the manufacturers engineering organization. Machine tool builders are providing engineering support for the production process by evaluating and implementing operational steps in the manufacturing process. Production issues which include ergonomics, tooling options, work holding fixtures, material handling systems, inspection, and work piece modifications to improve the manufacturability of machine parts are all evaluated simultaneously. As such, machine design has increased in complexity compounding the strain on engineering resources.

Executives Evaluate Engineering Value Chain

Machine tool OEM executives are identifying opportunities in their organization to streamline both new product development and the final assembly of machinery to improve delivery cycles while still providing quality engineering services. Modularity in machine design has been an enabler to efficient machine design over the years; however the benefits of modularity have reached a plateau. The industry needs to identify new methodologies that facilitate rapid concurrent design in conjunction with reusability of existing solutions.



Sequential, Iterative Design Model is Costly and Time Consuming

Machine tool engineering organizations are evaluating the entire value chain from requirements engineering through optimization of design methods. Mechatronics design, which is the synergistic integration of mechanical, electrical, and automation software engineering processes, is now under the magnifying glass as executives seek improvement in the core competency of their business. Overall, it is time to market, design optimization, and engineering efficiency that business leaders seek.

Current Machine Tool Development and Initial Concept Phase

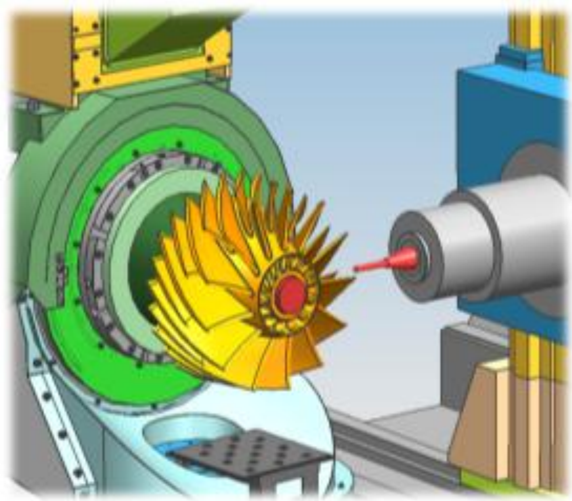
Requirements for wider operating ranges, increased functionality within the machine envelope, and increased reliability are being sought by manufacturers. Consequently, machine designers need to consider a larger set of possible solutions in an environment where time to market has become a driving force.

> The industry has lagged in the adoption of integrated design tools that span from the initial concept phase through the engineering design and development process.

Selecting the right components and leveraging the latest technology remains central to optimizing machine design. However, there are numerous inefficiencies in current machine tool development practices that create barriers to optimization. The industry has lagged in the adoption of integrated design tools that span from the initial concept phase through the engineering design and development process. Whether it is new product development or responding to a specific customer's requirement for a machine tool, the optimization begins in the initial conceptual design phase. It is in this early development stage that time is critical and the resource commitment on the part of the machine builder is most significant.

Concept Evaluation

MCAD design tools are widely used during the conceptual phase to evaluate footprint and functions, estimate final pricing, and illustrate geometric features that fulfill requirements. This conceptual phase is often referred to as "Lego engineering" in machine tool organizations. These conceptualizations are often 3D models of the machine tool and its major components; however they do not include dynamic properties. The ability to evaluate mechanical design alternatives based on dimensional geometry and ergonomic factors exist, but determining the optimal component selection based on dynamic properties is limited. Furthermore, these concept designs are loosely coupled to the systems design requirements and functional specifications. Requirements can be overlooked during the conceptual analysis leading to omission of critical functions in the overall machine tool design. This is further exacerbated as more production steps are incorporated in the machine tool envelope adding complexity to the design. Engineering organizations continue to operate in a serial, non-collaborative manner during the conceptual design process despite this increase in complexity.



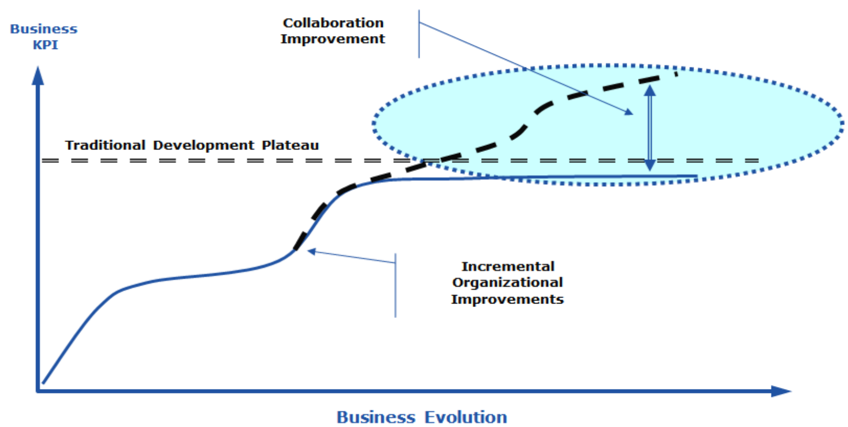
MCAD Models Conceptualize Physical Properties of Machine Tool Design, but are Loosely Couple to Functional Requirements

Capturing System Requirements

Typically, each engineering organization within the business (mechanical, electrical, automation software, etc.) develops standard documents in response to the customer requirements. These various internal engineering organizations each transform the customer requirements to yet another series of documents specific to their particular design discipline. For the most part, today's machine builders do not effectively associate machine tool specifications and requirements with specific components and design documents in each of the engineering disciplines.

Current Engineering Practices Inhibit Optimization

While some of today's machine builders have adopted informal concurrent engineering methods, more often, they rely on individual skill sets and established practices and knowledge that has been developed and passed down over decades of machine design. As the complexity of the machine requirements increase and design teams reach a threshold in numbers, informal concurrent engineering processes break down. Without a dependency chain in the design process, design constraints imposed within one engineering group are easily overlooked by others because a common functional model is not used across engineering disciplines.



Informal Concurrent Design Methods have reached a Plateau in Improving Business Performance

Problems arise from the fact that each engineering discipline uses design tools specific to their engineering domain. Mechanical designers use MCAD; electrical system designers use ECAD tools; and automation software developers rely upon development environments specific to automation systems.

Based on the conceptual mechanical model each engineering group optimizes the solution in their respective disciplines. However, the optimal solution within each engineering discipline will generally not result in an optimal system design. Designers are challenged by the limited opportunity to introduce alternatives once the design process is set in motion. Fundamentally, the integration of models between design disciplines is often difficult; however it is commonly thought that MCAD

The integration of models between design disciplines is often difficult; however it is commonly thought that MCAD tools alone are sufficient to tie engineering domains together.

tools alone are sufficient to tie engineering domains together. In reality, in many organizations, MCAD is just that; a mechanical system design tool with little or no capability to collaborate with other engineering disciplines.

Late Stage Design Alternatives Increase Project Risk

Typically, problems in an interdisciplinary design context occur when the engineering disciplines interface near the end of the design process. Often, these problems emerge due to incomplete or inexact connected interfaces between the detailed design disciplines of mechanical, electrical, and automation software. Late consolidation and difficulties with system integration has consistently been one of the primary causes of lengthy machine system development and the associated costs. According to the 10x rule, the propagation of errors at each integration stage cost 10 times the cost of original project estimates.

> Late consolidation and difficulties with system integration has consistently been one of the primary causes of lengthy machine system development and the associated costs.

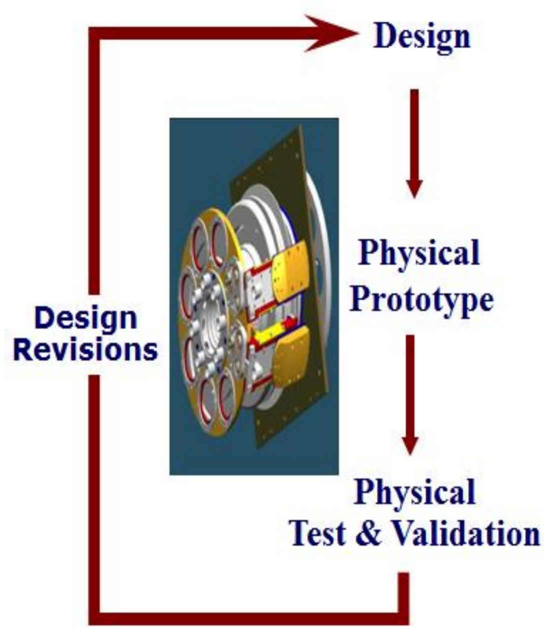
Designers are unable to evaluate principal design concepts and requirements at an early stage in machine tool development cycle. Today, engineering organizations don't have the ability to take a high-level perspective of the functional aspects of the machine until most of the detailed design has been completed. Integrated tools that address this problem are lacking in the industry. Only after the designers define essential design requirements can they begin to make tradeoffs or recommend alternatives. This results in further iterations in the late stages of the development process leading to project extensions and cost over runs.

Module Prototyping Widely Employed to Mitigate Integration Issues

Physical prototyping at various stages throughout the development cycle is widely employed to validate independent modules. This does not eliminate all integration issues. In complex machine designs, unexpected constraints encountered in downstream design activities can also inhibit the ability of the designer to meet the overall performance requirements for accuracy, dynamic response, and production throughput.

> Unexpected constraints encountered in downstream design activities can also inhibit the ability of the designer to meet the overall performance requirements.

One method machine tool builders use to address the requirements for physical prototyping earlier in the design process is the application of physics-based simulation. Simulation technology currently available in the market requires designers to develop complex analytical models that simulate dynamic interaction mechanical or electrical components. Moreover, the majority of simulation tools are primarily focused on mechanical modeling and there are not any products that are able to support an integrated view of multiple engineering disciplines. The current generation of simulation tools facilitates detailed subsystem analysis, but fail to satisfactorily address the overall machine system integration issues. Rapid and easy prototyping development tools are in dire need in the market to help mitigate the time constraints machine tool designers are confronting.



Conventional Development Cycles Relying on Physical Prototyping is Sequential in Nature.

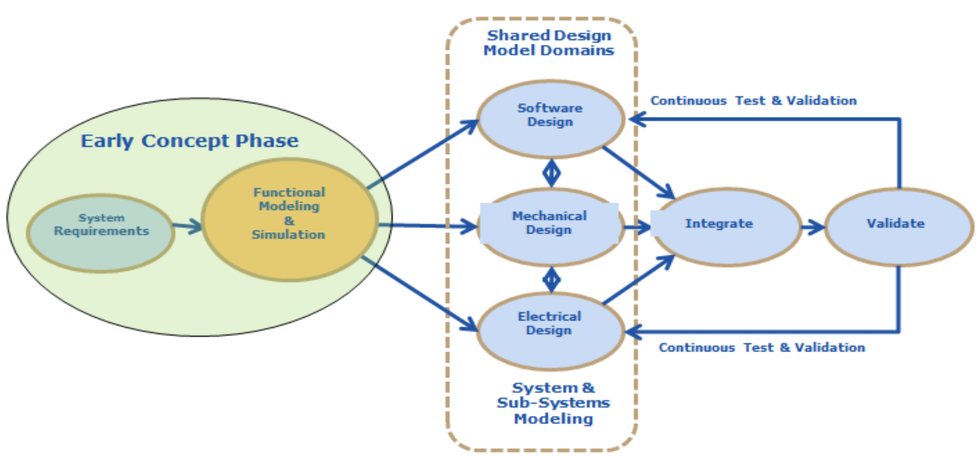
In machine tool design, real-world performance depends on how well the overall machine tool functions as an integrated system. A system-focused, mechatronic design approach not only enables designers to identify the best solution for any given set of requirements, but also ensures that all subsystems and engineering disciplines are functionally integrated per these requirements.

Future Technologies will Enable Early Machine System Validation

Many of the business challenges that are currently facing machine tool builders will be addressed by the emergence of next generation development platforms and state of the art simulation technology. Issues such as machine tool complexity, managing interdisciplinary engineering, extended development lifecycles, and shortened delivery schedules will be addressed with machine tool development environments that apply methodologies based on functional modeling, systems engineering, and advanced simulation technologies.

Functional Modeling Essential to Systems Engineering

The initial phase of the development process is where designers would benefit the most from a functional model of the complete machine tool system. A functional model results from the application of a systems engineering approach, where all of the functions within the modeled system are represented. Just as sub-systems can be decomposed from the overall systems requirements, a functional model represents the overall system requirements decomposed into the various functional components and elements of the total system. Such a functional model provides a conceptual view of the system and sub-systems. It also defines interfaces between the data management of the different disciplines and enables an accurate way to map requirements to specific system functions. Additionally, this enables the traceability of the customer requirements data down to the design departments. This ensures that all functions can be traced back to overall system requirements and the various engineering disciplines involved.



Development of a Functional Model is Critical in the Early Concept Phase

Early System Validation Shortens Development Lifecycle

Clearly, those elements in the overall machine requirements and specifications that drive design decisions and component selections should be addressed early on. The capability to evaluate alternatives much earlier in the design cycle leads to innovative solutions that meet performance and cost objectives, as well as streamlining the entire development process. The use of a systems engineering based mechatronic development platform facilitates early validation.

> Designers are able to develop a functional model that captures all requirements of the machine tool system, allows better concurrent development practices among the various engineering disciplines, and validates system functions at each stage of development.

The added complexity of mechatronic development means that machine tool builders need an organized, collaborative platform that will enable them to take a functional, model-based design approach at an early stage in the development process. This enables designers to develop a functional model that captures all requirements of the machine tool system, allows better concurrent development practices among the various engineering disciplines, and validates system functions at each stage of development. The earlier in the overall design process that functions can be validated, the faster and more efficient the overall development process can become.

A collaborative development platform that supports an interdisciplinary development environment reduces the occurrence of design changes. Late stage changes can be avoided altogether through the development of a conceptual functional model that captures all engineering discipline interfaces early in the process. This can significantly reduce development time and subsequent project cost overruns. Overall, such a mechatronic development environment addresses the major issues of time-to-market and complexity.

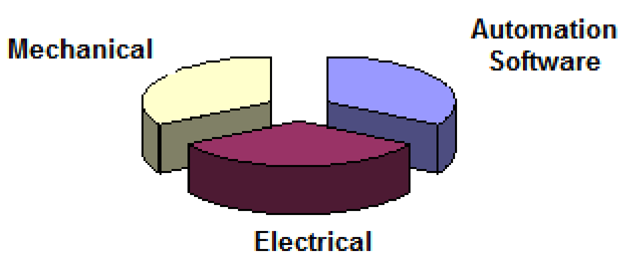
3D Simulation Allows Virtual Validation of the Complete System Design

3D simulation tools provide a key technology enabling early validation of multi-discipline systems. These tools virtually simulate and validate the physical definition of the machine design concept, functional requirements, and behavior of the interaction of subsystems. Significant progress has been made in physics-based simulation by the application of today's advanced gaming engines, which can now be leveraged by industrial manufacturers. Moreover, a physics-based simulation solution that is designed to analyze the physical interaction between machine tool components allows the systems design engineer to simulate and validate motion and force, general machine dynamics, kinematics, actuators, servos, as well as detect collisions and interference with tooling and fixtures. Using these simulation tools, the designer can target specific component objects to determine actual physical characteristics, behavior, and actual physical runtime parameters such as position, speed, and rotation.

Next Generation Physics-Based Simulation Uses Gaming Engines

The aim of system-level simulation is not to conduct detailed analysis and validation of the specific characteristics (vibration, thermal, frequency response, or stress) of individual components, but to simulate the overall machine system and the behavior of the interaction of the various engineering design disciplines. One advantage of this type of simulation is that it enables the machine tool systems designer to model and validate component-to-component interactions in conjunction with the overall system behavior. This also allows designers to more accurately specify components, like motors and actuators, based on a virtually simulated machine tool model.

An interdisciplinary development platform enables the designer to evaluate mechanical and electrical component designs jointly, long before any physical prototyping or testing is possible. In an early systems-level simulation environment, the various engineering disciplines can work together with a single model on a common platform to develop and refine requirements for the individual sub-systems. Once validated, the detailed design can be addressed using tools relevant to each discipline.



An interdisciplinary development platform enables the designers to evaluate mechanical and electrical component designs jointly, long before any physical prototyping or testing is possible.

Typically, a mechanical designer will create the design based on 3D shapes and components, and mechanical attributes such as kinematics, gears, cams, etc. Working on a collaborative simulation platform, the electrical systems designer can participate in selecting and positioning electrical components such as sensors, actuators, and servos. Additionally, the automation software functions can be included in the simulation model to validate that the automation software design conforms to the functional model. The automation and controls engineer can use the mechatronics development platform to design the basic logic control of the machine as well as motion and kinematics programming. Automation software developed in this environment can define both time-based behavior and event-based control.

Design Reuse and Modularity Essential to Mechatronic Systems Development

Engineering design reuse has become an essential element of any design project. To optimize and reduce the design lifecycle process, engineers must be able to access and retrieve design components and modules from existing designs. Reuse and modularity are keys to maximizing design efficiency, especially in multi-discipline mechatronic systems.

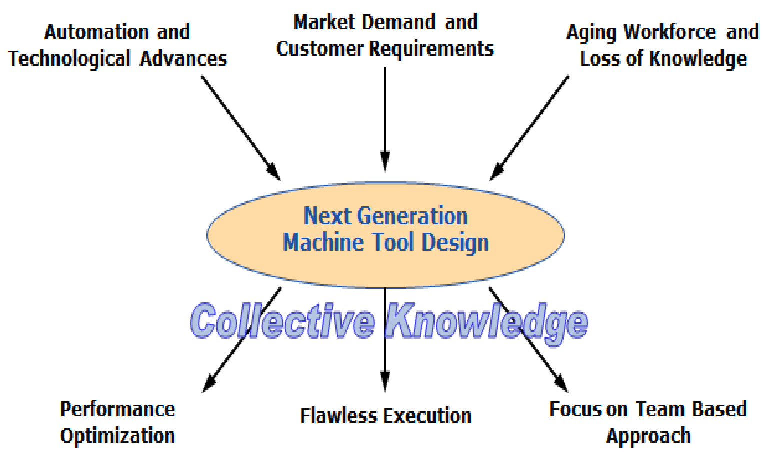
To improve speed to market, mechatronic development platforms must have reuse mechanisms and component libraries. The ability to capture knowledge from the design of components (which not only includes the mechanical design, but also the electrical and automation software design) and store these in a virtual object library would enable designers to reuse this knowledge in other machine tool projects. More and more, individual components are being designed with embedded intelligence capability that provide built-in "knowledge "of the specific functions of the component as it relates to the machine system. Capturing and retaining this knowledge could significantly reduce new project development time. Moreover, reuse enhances design quality because established designs are based on proven concepts and design intent. And, importantly, reuse accelerates the development process because the design engineer is relieved of repeating design tasks that already have been performed.

The ability to capture knowledge from the design of components and store these in a virtual object library would enable designers to reuse this knowledge in other machine tool projects.

The adoption of mechatronic development platforms and simulation technology will allow machine tool designers to more effectively deal with the development issues they face today. Use of functional modeling for conceptual design, the ability to virtually model, simulate, and validate the machine tool system, and significantly improved reuse methods will give those machine tool builders that adopt these tools a definite edge in the market.

Conclusion

Clearly, multiple business challenges confront today's machine tool builders. These include a highly competitive market and customer demands driven by tight capital equipment budgets and significantly shortened delivery times. Customers also demand smarter machines, longer lifecycles, easy maintenance, and reliability. All this increases the overall complexity in terms of managing the design process across an interdisciplinary engineering environment consisting of mechanical, electrical, and automation software design elements. Unfortunately, this complexity results in longer design and development lifecycles at a time when customers demand sig- significantly shortened delivery times.



To respond to customer requirements while remaining competitive and profitable, machine tool builders need to both adopt a systems engineering design approach and improve their concurrent engineering practices.

To respond to customer requirements while remaining competitive and profitable, machine tool builders need to both adopt a systems engineering design approach and improve their concurrent engineering practices. Essential elements for a systems engineering-based machine tool development platform include functional modeling capabilities that ensure that all requirements are met in the machine tool design across mechanical, electrical, and automation software disciplines. Additionally, developers need to be able to virtually model, simulate, and validate the complete machine tool system in 3D to determine that it meets all requirements in terms of functionality and physical behavior.

For machine tool builders to confront and deal with the dual challenges of reduced time-to-market and increased complexity, they must have tools, platforms, and processes that will mitigate these issues. Additionally, to achieve constant innovation in a demanding, competitive market, they must be able to streamline their upfront concept design phase and improve alternative selection processes to enable designers to focus on product improvements and customer demands, rather than being burdened with managing project delays, cost overruns, and design changes.

Analysts: Dick Slansky and Sal Spada

Editor: Paul Miller

Acronym Reference: For a complete list of industry acronyms, refer to our web page at www.arcweb.com/Research/IndustryTerms/

API Application Program Interface
B2B Business-to-Business
BPM Business Process Management
CAGR Compound Annual Growth Rate
CAD Computer Aided Design
CAM Computer Aided Mfg
CMM Collaborative Management Model
CPG Consumer Packaged Goods
CPM Collaborative Production Management
CRM Customer Relationship Management
ERP Enterprise Resource Planning
FAT Factory Acceptance Testing
FEA Finite Element Analysis
HMI Human Machine Interface
IOp Interoperability
IT Information Technology
MIS Management Information System
OEM Original Equipment Manufacturer
OpX Operational Excellence
PAS Process Automation System
PDM Product Data Management
PLC Programmable Logic Controller
PLM Product Lifecycle Management
RFID Radio Frequency Identification
ROA Return on Assets
SCM Supply Chain Management
WMS Warehouse Management System

Founded in 1986, ARC Advisory Group is the leading research and advisory firm for industry. Our coverage of technology from business systems to product and asset lifecycle management, supply chain management, operations management, and automation systems makes us the go-to firm for business and IT executives around the world. For the complex business issues facing organizations today, our analysts have the industry knowledge and first-hand experience to help our clients find the best answers.

 This research has been sponsored in part by Siemens. However, the opinions expressed by ARC in this paper are based on ARC's independent analysis.

You can take advantage of ARC's extensive ongoing research plus experience of our staff members through our Advisory Services. ARC's Advisory Services are specifically designed for executives responsible for developing strategies and directions for their organizations. For membership information, please call, fax, or write to:

ARC Advisory Group, Three Allied Drive, Dedham, MA 02026 USA
Tel: 781-471-1000, Fax: 781-471-1100, Email: info@arcweb.com
Visit our web pages at www.arcweb.com

ARC
arcweb.com

3 Allied Drive Dedham, MA 02026 USA 781-471-1000