

The adaptive machine

Achieving batch size one

PERFECTION IN AUTOMATION
A MEMBER OF THE ABB GROUP



The adaptive machine: Design strategies & attributes

Dedicated machine designs are giving way to more flexible concepts featuring base modules that can be configured to match production requirements and reconfigured as needed - enabling true batch-of-one operations.

The result is a whole new category of machinery: *the adaptive machine*.

This paper discusses the attributes that make a machine adaptive and the enabling technologies behind the movement.



A new business model for a new consumer



It could be said that it is a new generation of production technology for a new generation of consumer. Amazon and eBay have had a clear impact on the shopping mall business model. This is a generation that expects to get exactly what it wants, with immediacy, and these logistics models deliver.

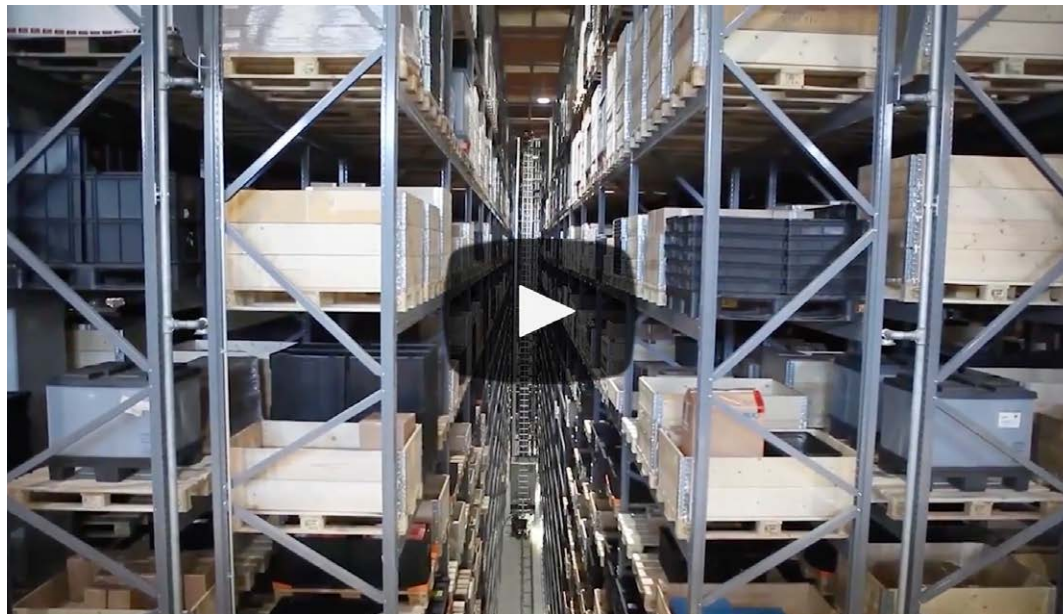
How does a traditional food, beverage or other consumer goods manufacturer leverage their core assets to innovate?

[Coca-Cola Freestyle](#), for example, combines innovations in product, product delivery, customization at the point of sale, and the ability to communicate your personal blend of beverages from smartphone to fountain.

Another approach is the smart factory, delivering batch size one via e-commerce.

Batch size one: The ultimate goal

Batch size one has become a practical reality – and in some applications may be the only realistic approach. In B&R's own manufacture of industrial PCs, for example, there are 250 billion possible configurations – so make-to-stock is not an option. Cost effective, efficient batch-of-one manufacturing is the only alternative in B&R's smart factory, which has been operational since 2009.

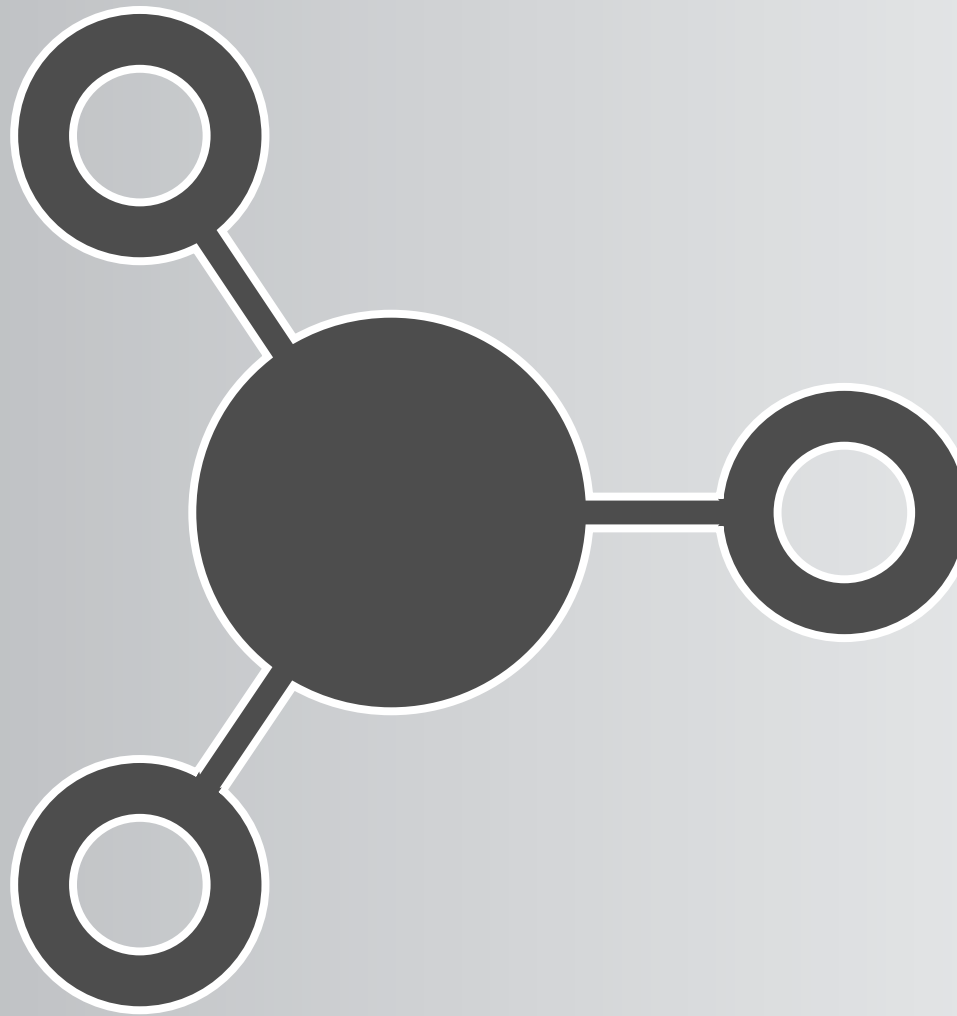


Today, automation technologies are being commercialized that put smart-factory functionalities in the realm of real-world production and packaging. This new generation of machinery is a must if producers are to cost effectively meet the expectations of consumers who are increasingly used to getting precisely what they want, quickly, online.

While additive manufacturing is a promising approach in many applications, it is not applicable to the majority of food, beverage, pharmaceutical and household goods production processes. Therefore, it will not be a subject of this paper.

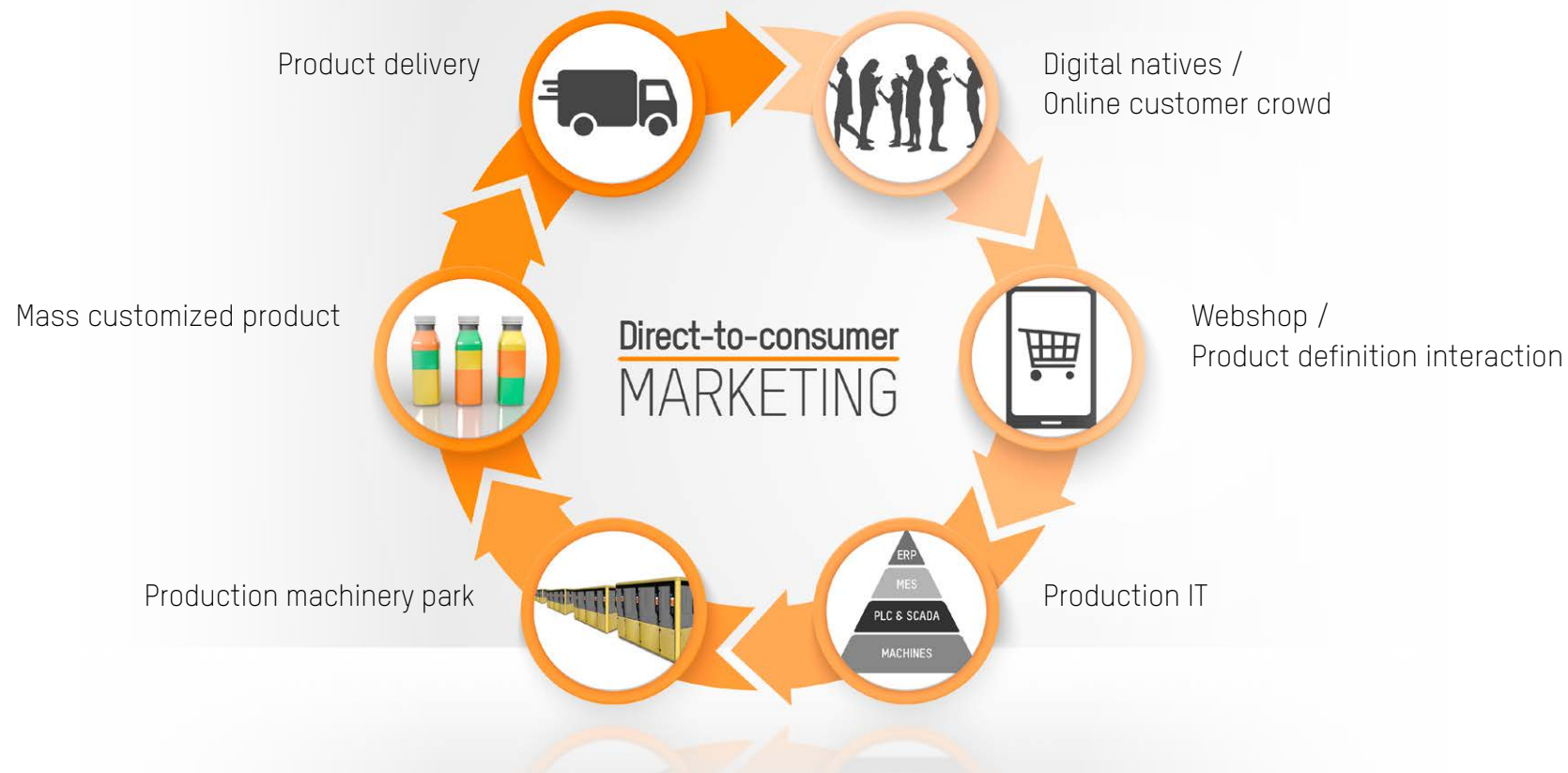
Production lots comprising *literally one product* also don't fit every product category, yet the same technologies apply to automation of rainbow packing, mass customization, short production runs with frequent changeovers and producing limited time offers. Batch size one is the ultimate invocation of these marketplace trends.

Core capabilities



The following pages will define the core capabilities of the adaptive machine and how they will power the profound economic impact of this new machine generation.

Enabling e-commerce from the production line



While e-commerce retailers are investing in massive distribution centers, batch size one allows customized products to ship directly from the manufacturing line to the consumer.

The obstacle has been the ability to produce batch size one economically.

Manufacturer as sales channel



With practical batch-of-one manufacturing and packaging capabilities, manufacturers are able to skip the added steps and cost of e-commerce resale and instead go direct-to-consumer. This has the potential to reverse the chronic power shift from manufacturer to sales channel.

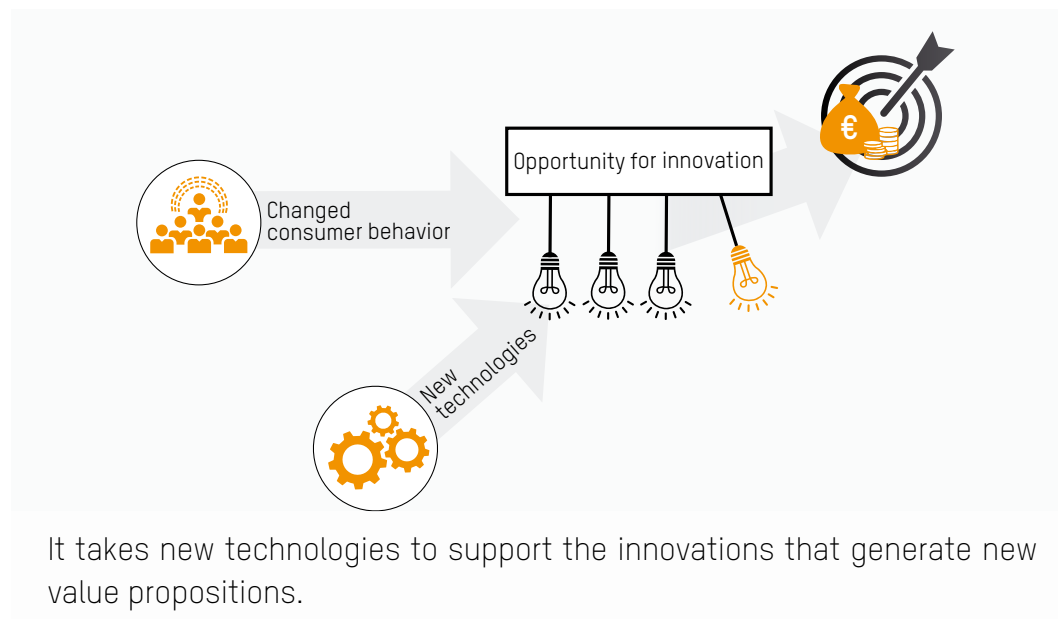
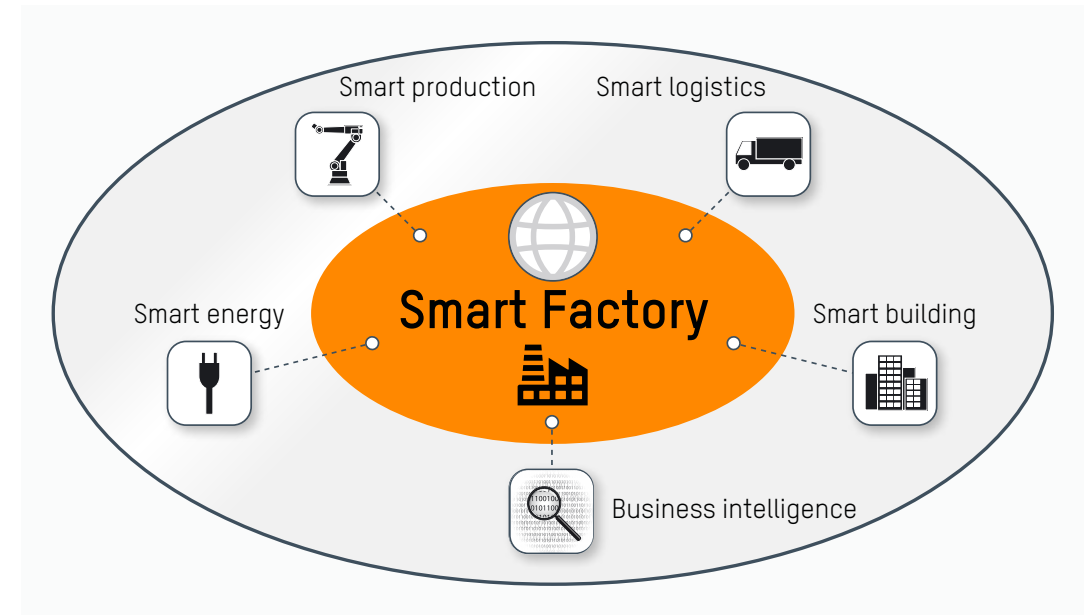
Batch size one also serves to reduce the cost of raw material and

finished goods inventory, the overhead cost of regional distribution centers, the cost of servicing wholesale and retail sales channels and the discounting/disposal of unsold inventory. Several of these benefits apply to e-commerce resellers as well.

While batch size one has been elusive, its appeal to manufacturers is quite clear.

Enabling the smart factory

Adaptive machines put smart factory functionalities in the realm of real-world production and packaging applications. This new generation of machinery is required to cost effectively meet the expectations of consumers:



- Changeovers become obsolete, replaced by the ability to change both product and package format with every cycle.
- Accumulation is replaced by synchronization via parallel processing to balance production times of dissimilar products.
- Reconfiguration is replaced by switching out machine modules on a highly flexible base machine.
- All enhanced with IIoT capabilities such as analytics, process optimization, predictive maintenance and other productivity tools.

Adapting to the unknown

Reducing time to market for new products and changes in products

Switch from glass bottles to plastic, or from rigid to flexible containers, and you need a completely different set of filling and packaging machinery. The lifecycles of consumer products and packaging keep shrinking, while SKU counts continue to grow. Given the 15 to 20+ year service life of industrial machinery, it is no longer possible to anticipate all the changes that will occur – especially the disruptive ones.

The adaptive machine will support on-the-fly changeovers and allow reconfiguration with different production modules using the same base machine platform. It will readily adapt to constant changes in size and format. But it will also adapt to radical and unforeseen requirements through corresponding equipment changes, such as replacing a carton erector module with a pouch forming module.

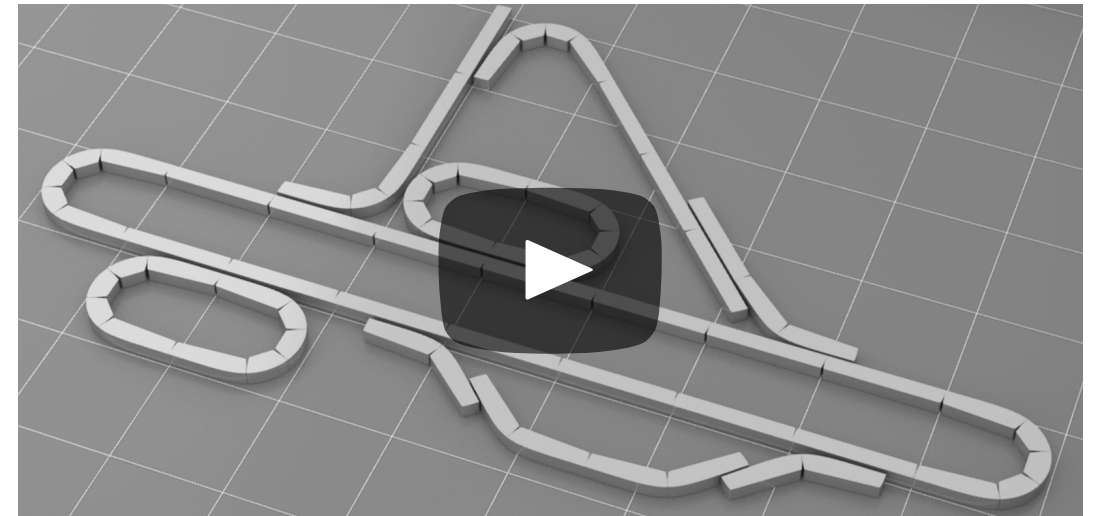


As lot sizes shrink and throughput requirements (leadtime and volume) remain critical, adaptive machinery will compare favorably in all aspects of productivity measurement – OEE, ROI and TCO.

Redefining flexibility

New-generation track systems are variable pitch, meaning that each shuttle is controlled independently. Their movements can be synchronized to prevent bottlenecks and eliminate the need for accumulation buffers.

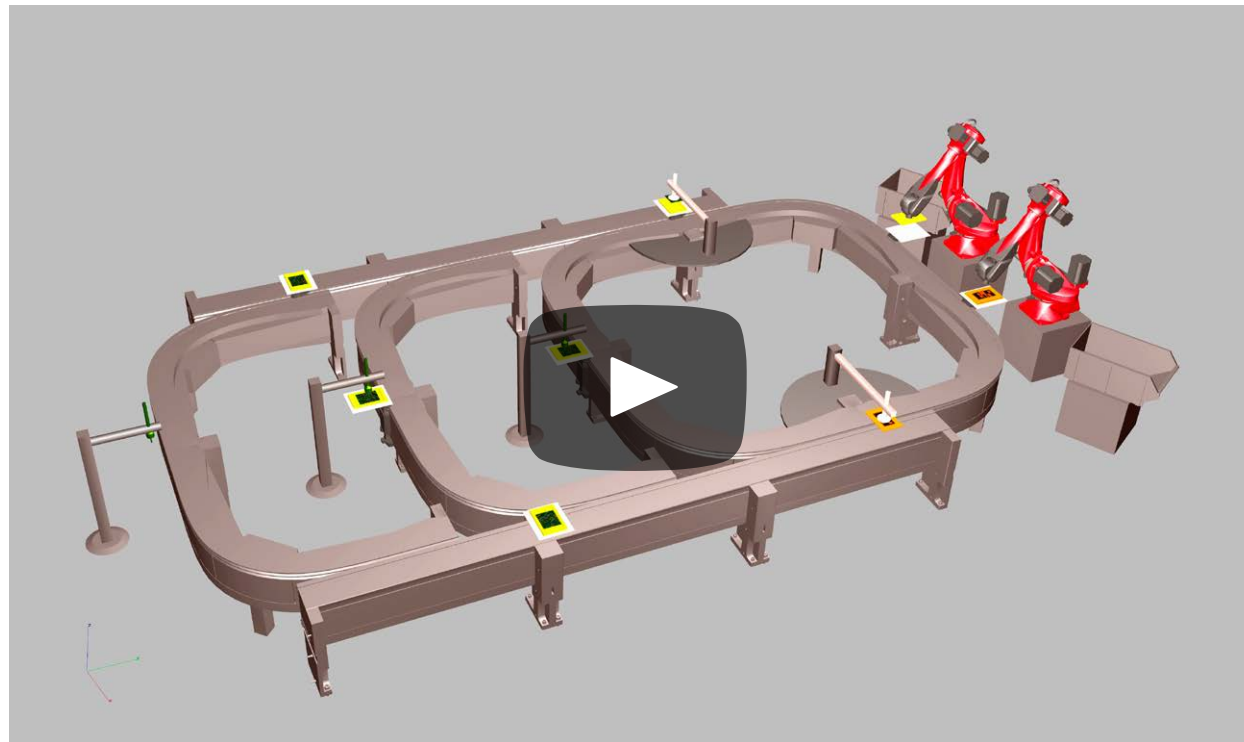
A shuttle with a payload that requires 4 seconds to process, for example, can be synchronized with a process that performs a 2-second process on two shuttles, or a 1-second process on four shuttles, and so on. Well planned variable-pitch operation optimizes production efficiency.



The latest generation of track technology adapts to the needs of the process and not the other way around.

Current linear track systems can mount horizontally or vertically for added flexibility without reducing bearing life. And they can be positioned around obstructions such as existing building columns. It is important to note that current-generation tracks can utilize workspace above, below, inside and outside the track. Older designs could not, because spaces were filled with componentry.

Parallel processing and load balancing



The adaptive machine can increase line productivity – and not just by 5 or 10%, but much more drastically. Why? Because with traditional fixed-indexing product transport, productivity is limited by the slowest station. The adaptive machine multiplies productivity with an elegant solution – by allowing multiple instances of slower stations.

The productivity gain can be substantial and is determined by the difference in processing time between the fastest and slowest stations. The latest generation of track technology permits processing on parallelized lines enabled with load-balancing technology. All in all, the adaptive machine is a real game changer for productivity.

Higher productivity per square meter



Floor space is precious. The adaptive machine follows a rigorous design approach that minimizes space requirements. The adaptive machine relies on compact automation components with high power density.

The result is increased productivity per square meter of floor space – and a corresponding boost in return on investment. Adaptive machine technology helps to get the most out of a building's infrastructure.

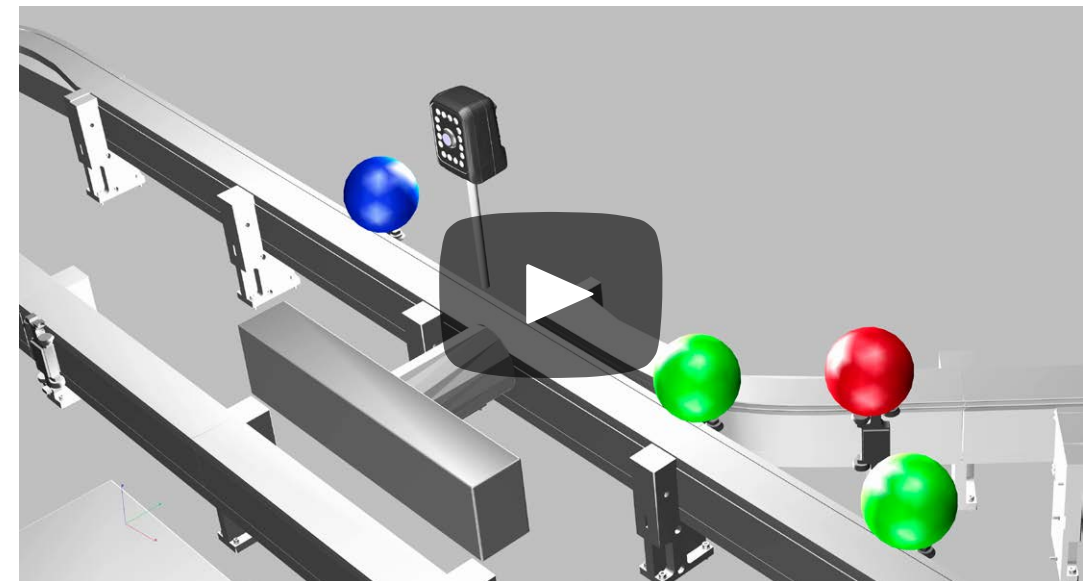
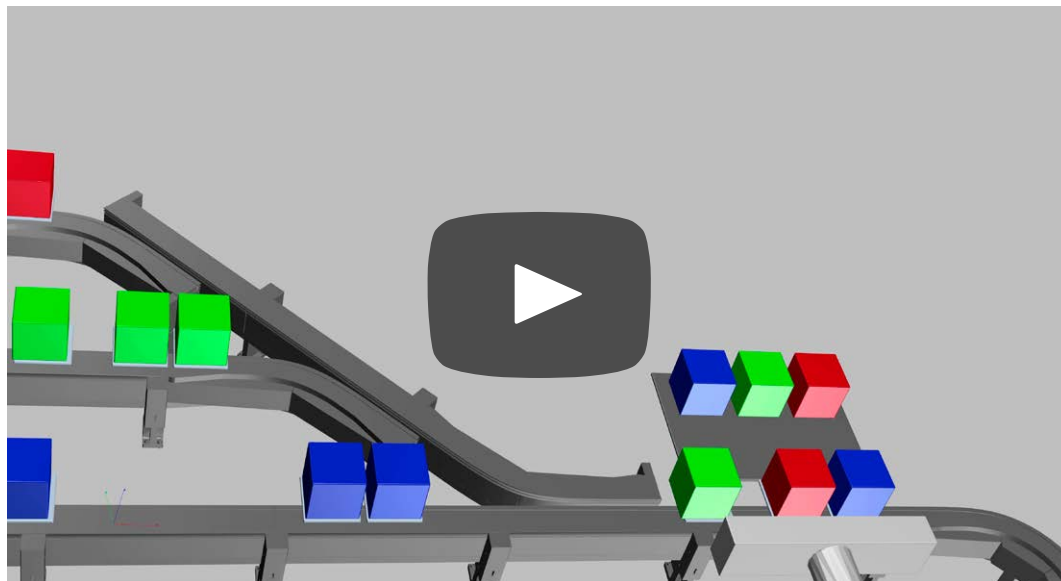
Investment security through scalable machine technology



An unavoidable challenge that comes with the pleasure of operating in a growth market is that, sooner or later, installed capacity will reach its limit. Continuing to serve the market's needs means investing in capacity extension. Traditionally, this meant choosing between adding machinery or replacing outdated equipment with more modern, higher-productivity equipment.

Now, the adaptive machine brings an attractive new option: scalable machine architecture. By adding new track segments and additional processing stations, a machine's installed capacity can be easily upgraded with minimum investment. This is true investment security and future-proof ROI.

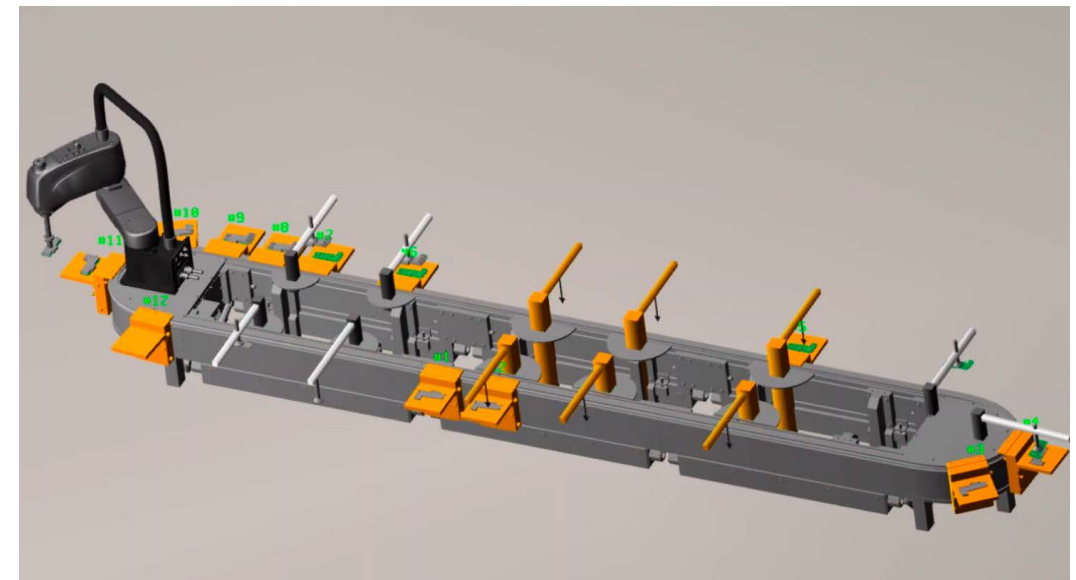
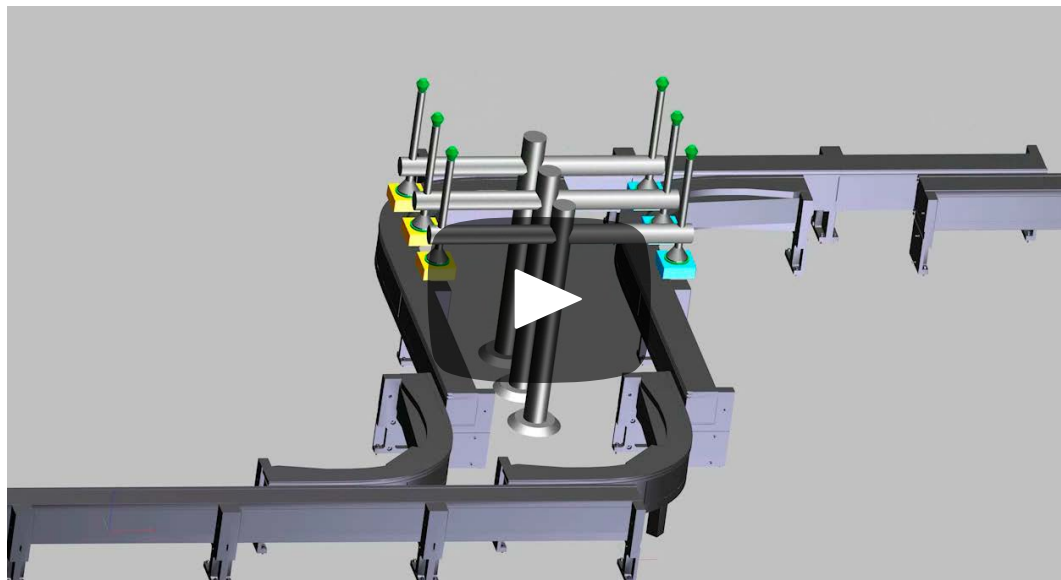
Merging and dividing product flows



High-speed diverters in the latest generation of track systems allow product flows to merge and divide responsively and in real time. The adaptive machine makes extensive usage of these benefits. Whether it's cost-efficient batch-of-one production without any changeover whatsoever (think composition of custom sets or rain-

bow packs) or sorting out defective products on-the-fly and on a product-by-product basis. The adaptive machine elevates the availability component of OEE to a level that that makes batch size one economically attractive – and paves the way to total quality production.

Inherently fault tolerant



Flexible product transport in an adaptive machine gives producers an exceptional level of fault tolerance. Traditionally, a problem at one redundant processing station has resulted in faulty products that need to be sorted out further down the line. The cost for the products themselves and even their packaging is lost. The adaptive machine is able to handle this situation

much more intelligently. With a quick tap on the HMI screen, the operator simply disables the faulty station and the product transport system will no longer send products there. Production continues at maximum quality with a slight decrease in output rate. The adaptive machine opens up new dimensions of resource efficiency and boosts the quality factor of OEE.

Maintain control over product at all times

Physical control of product and packaging has a subtle, yet critical, impact on efficiency and consistency and should not be lost in the transition between processes. The uncontrolled product flow typically found in bottling lines can lead to scuffing, line jams and product loss.

In conventional packaging lines, control is maintained by fitting conveyors with lugs, pucks or even vacuum belts. In assembly and machining lines, parts and products may be fixtured on jigs, "tombstones" or pallets.

Both approaches tend to be rigidly sequential.

In the adaptive machine, fixturing still may be used to maintain positive control over the product, but in a much more flexible environment. Variable pitch, multidirectional travel and syn-

chronized movements of the shuttle, robot arms, actuators, printheads and other devices mean that the process adapts to the product, not the other way around.



Math over physics

Automation providers continue to develop algorithms that compensate for physical, mechanical and electrical limitations.

In combination with the new track technology, anti-sloshing allows open containers of liquids to be moved faster without spilling. This motion control software functionality provides precisely controlled, gentle acceleration and deceleration despite fast movement.



Anti-sloshing algorithms seem to defy the laws of physics.

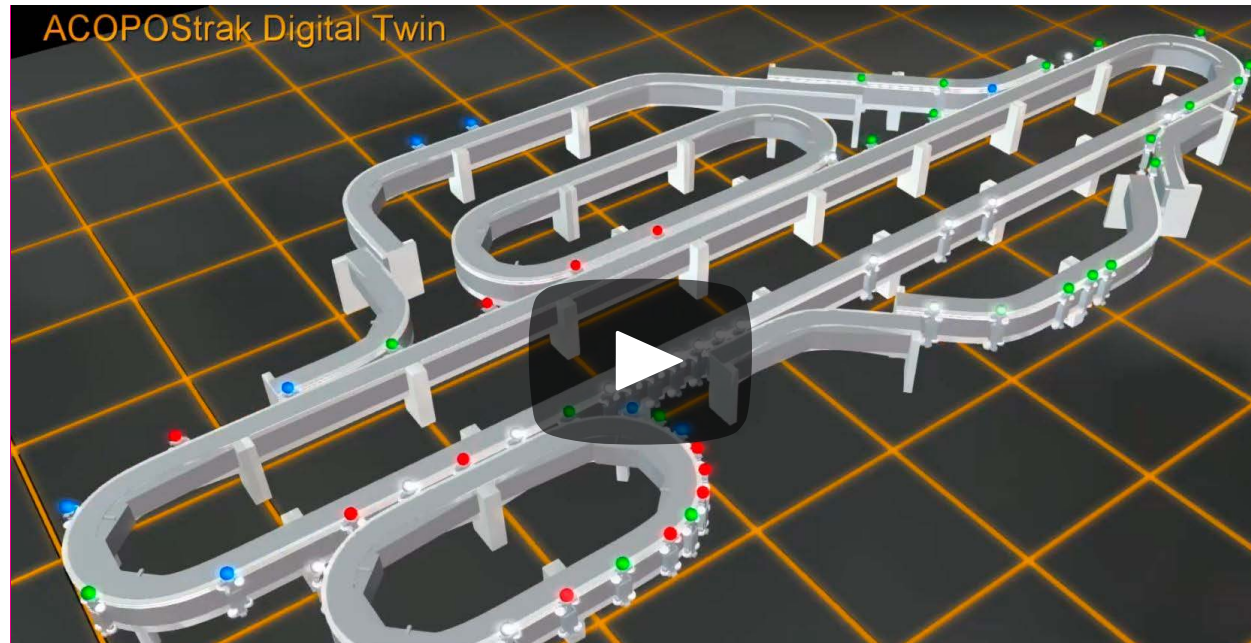
Likewise, certain mechanical conditions can cause periodic disturbances in servo-controlled machinery. A repetitive control algorithm can be used to predict and compensate for those fluctuations. It's an active form of suppression that undergoes a constant learning process to adapt to changes in disturbance, such as may be caused by wear.



Repetitive control algorithms undergo constant learning to adapt to mechanical fluctuations.

Digital twins

Simulation vs. prototyping



The off-the-shelf modularity of adaptive machine subsystems makes simulation tools practical.

One of the most effective design tools for testing multiple variables prior to cutting metal is simulation. Traditionally, simulation hasn't been widely applied on purpose-built machines because they tend to be variations on established designs or so highly customized that simulation is considered cost prohibitive.

With the advent of racetrack modules, the automation supplier has the justification to provide simulation capabilities as part of

the solution. With these systems, there actually is no prototype. Machine modules are configured rather than built from scratch. The customization lies more in layout, tooling and fixturing, as well as in optimizing the number, movement and dimensions of devices, shuttles and workstations.

These variables are ideally suited to simulation, and the result is an optimized design achieved faster and at lower cost.

Early adopters



The following pages will examine a few early adopters of the adaptive machine who have already begun shaping this new machine generation.

Rotary labeling machines



Rotary labelers are an example of modular machine design available today that can adapt to paper, film, cold glue, hot melt, self-adhesive, wraparound, front/back and neck labels and more. The corresponding modules, known as aggregates, are wheeled in and clamped into place. These examples come from Italy.

By controlling bottle plates individually with servo motors, each becomes an independently controlled zone – an essential feature of the adaptive machine concept. Rotary labelers gain the flexibility to run different sizes and shapes of bottles – round, square, oval, flask – that previously required different machines or impractical belt or cam changes.

Rotary labeling machines



This example from the U.S. features pharmaceutical serialization, where each container is tracked and traced individually - another hallmark of batch size one.

Turning robots into filling lines



This company, based in Asia, has taken an off-the-shelf approach that represents another evolutionary step toward the adaptive machine. They've implemented filling heads as end-of-arm tooling on robot arms, holding containers in pucks to maintain control, and recreated the inline motion profile of a walking beam.

Their initial design strategy for using robots? They had never designed a packaging machine, so they opted for commercially available robot arms and synchronized them with the conveyor system – effectively achieving the modularity and reconfigurability aspects of an adaptive machine.

The adaptive case packer



An adaptive case packer from Tavail erects, fills and closes up to four different sized cases on demand, at rates of 20 cases per minute, capable of changing case sizes in 4 seconds or less, programmable with 99 recipe-driven case formats and corresponding lid formats.

It's mass customization without a throughput penalty. And it is well suited to e-commerce fulfillment because shippers like FedEx and UPS are now charging by package size in addition to weight, creating an imperative to minimize voids.

The adaptive labeler



Introduced to the European market at Drinktec 2017, the Leap track based Gen4 labeling system from Makro Labelling takes servo control of bottles to a new level.

The video shows how two shuttles on two tracks are synchronized to control container movement, while a third shuttle uses linear motion to turn the container for label application.


With multiple label applicators, different labels can be applied in line, whether for different bottle sizes or shapes, or different products or flavors for batch size one.

The adaptive bottle filler



At the same trade show, Krones introduced “bottling on demand”, for batch-of-one filling and capping with the ability to produce rainbow packs of any combination in line. This Gen4 system also uses track technology to produce and collate customized orders, ready for secondary packaging.

This compares favorably to packing, shipping to a distribution center, unpacking, and laboriously repackaging into variety packs.



Impact of the adaptive machine on the packaging sector

A new fourth generation of packaging machinery, possessing the attributes of the adaptive machine, is now entering the marketplace. With Gen4 comes the long anticipated flexibility to solve the challenges of mass customization, e-commerce fulfillment, SKU proliferation, inventory costs, shorter product lifecycles, track-and-trace and manufacturing productivity.

What led to Gen4 packaging machinery?



Until recently, Gen3 was the pinnacle of packaging machine design.

The three previous generations of packaging machinery have been documented by OMAC, the Organization for Machine Automation and Control:

Gen1 – mechanically driven machines, typified by a central motor powering a line shaft, connecting to jack shafts synchronizing machine functions. Gen1 machines rely heavily on manual changeovers requiring tools and change parts.

Gen2 – with the introduction of servo motors to packaging machines, servos were first added to existing mechanical designs to add more automation. However, because the machines re-

mained largely mechanically driven, Gen2 increased complexity without significantly increasing performance.

Gen3 – by interpack 1999, a prominent European packaging machinery builder declared their new servo machines, designed from the ground up for servo automation, to be a third generation. The line shaft was gone, and thanks to recently developed multi-axis servo control technologies, all machine functions were synchronized over a digital motion network. Today's Gen3 machines are also referred to as mechatronic designs, integrating the disciplines of mechanical, electrical and software engineering.

Gen3 and Gen4 packaging machinery



Gen4 machines are adaptive, delivering the flexibility to economically achieve mass customization.

Over the past nearly two decades, Gen3 machines continued to evolve in important ways through automation technologies that enabled recipe-driven operation, restarting without re-homing, tool-less and even automated changeovers, robotic flexibility, reduced product giveaway, serialization – and literally dozens of new capabilities.

Gen3 machines can certainly be modular, yet they tend to be dedicated designs and changeovers are still required for format changes. Mass customization – even automated rainbow

packaging, let alone batch size one– have remained elusive goals until now.

Gen4 packaging machinery delivers the ability to achieve mass customization without sacrificing efficiency. Gen4 technology fulfills the promise of Industrial Internet of Things/Industry 4.0. And it provides enabling technology to achieve Packaging 4.0 strategies. By delivering the flexibility and performance of adaptive machine technology, Gen4 represents an all new generation.

Conclusions



- Adaptability pertains to changing consumer expectations, market strategies, products, packaging and line extensions
- Adaptive machines feature independently controlled modules with multidirectional movement, tight synchronization with other (often robotic) devices and exceptional flexibility
- New and next-generation linear track systems form the backbone of the adaptive machine – unlike conveyors, track systems can perform work on products while in transit
- When researching adaptive machine solutions, consideration should be given to complementary production technologies as well as to the level of advanced automation technology enabling the adaptive machine
- The business case for the adaptive machine is justified as batch size shrinks and throughput requirements remain critical – and is measurable by proven methods (OEE, ROI, TCO)



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