Automation of Essential Services

Dan Slomski
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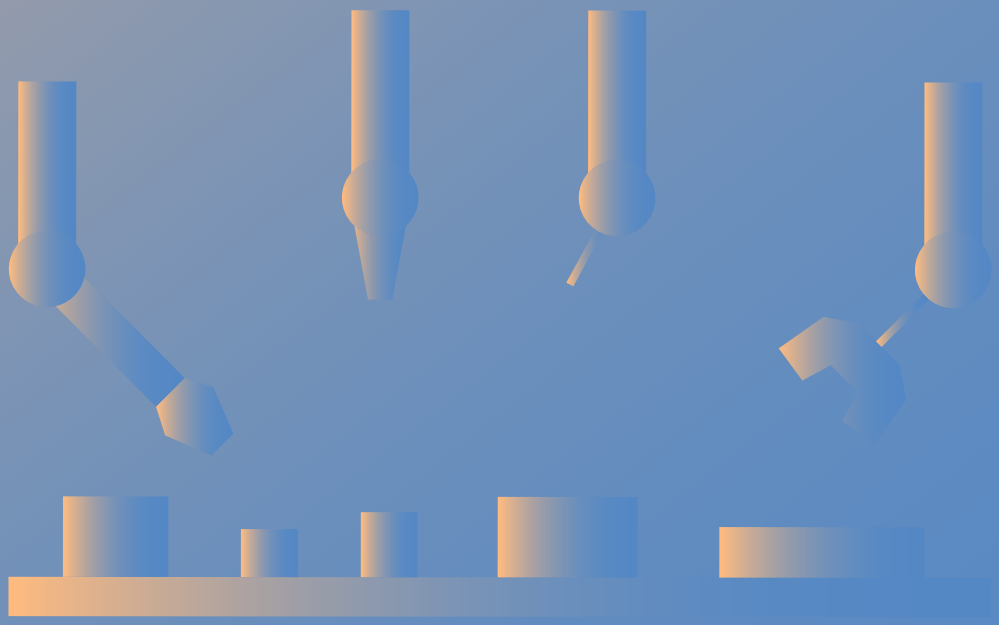


Prime Movers Lab

No one could have predicted the magnitude of the disruption caused by COVID-19 and the resulting shutdown of the global economy. While we are still scrambling to understand the biological aspects of the pandemic, the more direct impact may be the untallied economic damages of the Great Pause. Some estimates predict that economic recovery could stretch out for years to come. This disruption is the stuff of science fiction, the global workforce sent home and production halted in all but a few key industries. Except for the tasks that can be done remotely or those deemed essential, most of the world labor force cannot work.

For those that are considered Essential Workers or Essential Businesses, they have the right to continue working during the lockdown, providing services necessary to keep the fabric of society together. But while some are permitted to keep working, others, such as medical staff and grocery workers are more truthfully being forced to. I have a number of friends that work in essential retail, grocery, or Amazon, that do not have a choice to stay home even to protect themselves. They must go in daily to make sure the flow of goods continues.

Considerations in Any Automated System

Reliability
Reliability is a measure of the ratio of time in an instrument's life when it can be expected to function as designed and when desired. Essentially, does it work the way you want, when you want it to? A closely related concept is availability, which measures whether a system is able to operate when it is supposed to be able to.

Everyone wants a reliable system that never breaks and never fails to do the task it was designed to do. But reliability comes at a steep cost in hardware design, and is one of many factors that must be balanced when designing a system or production line.

Let's consider an example of a robotic inspection camera on a conveyor belt, tasked with identifying correct hole spacing on some molded plastic shovels passing by on the belt below. This robot might only need to be 95% accurate at identifying a faulty part as it goes by, which might match a human worker performing the same task. So out of 20 failed parts, 19 get correctly identified, and 1 bad part slips through. But that might be okay, since downstream there is a process step where the handle is aligned and attached to those holes. That step is also likely to catch the erroneous part. And even if it didn't, the consequences for a failed shovel coming off the line are fairly low. As such, this camera system can probably be quite cheap and relatively simple.

Conversely, consider what might be needed for a component going into a life-critical medical device such as a respirator, which may need to correctly analyze a failed component to 99.9999% reliability. In fact the Six Sigma methodology that is popular in name actually has its roots in reliability testing. Compliance with Six Sigma manufacturing indicates reliability down to approximately 1–3 defects per one million units produced, though the methodology extends beyond just reliability testing.

Another closely related measure would be **utilization** or usage-factor, which accounts for how often a machine is actually in service in a time period. This takes into account human operators, work-shifts (nights and weekends), and material supply shortages in addition to down-time that might be necessary for maintenance and repair.

Right now in Covid-19 lockdown, we are experiencing a very low utilization rate on our workforce, with most of our machines sitting idle while the human operators are stuck at home unengaged. Meanwhile the reliability of our supply network is being put directly to the test, especially in the early days of the pandemic, with stretched supply-lines for such products as N95 face masks, hand sanitizer, ventilators and

test kits. In truth, our supply chains for many items have broken, even though we have not yet begun to feel the impacts. A vast array of other products are dwindling in supply as we draw down stockpiles that most of us have no transparency to. I predict shortages on many unexpected products in the coming months; products that are not being made today without people. Meanwhile many other products with mature automated production lines will see no long-term shortages no matter how long the lockdown might remain in effect.

Throughput and Yield

Throughput is how much output can be expected per unit of time. Kilograms per day, or units per month are common throughput measures for material production and finished product assembly. Lab throughput could be described as how many tests can be run or analyzed in a day, or a week.

Yield is typically used to describe the proportion of output product that meets functional specifications. For a process in steady-state with a 95% yield, 95 units out of 100 that roll off the end of the line can be expected to be acceptable. It's often insightful to ask what happens with the failed quantities. Can they be recycled, or does this go on the books as total loss, and thus amortized into the price of the other 95 salable units?

For production instruments and automated equipment it can be very costly to troubleshoot a failing device. So it can be tempting for shops to keep equipment in operation even as yield drops, expecting the downstream quality-control department (either human or machine inspection) to catch the failing componentry and keep it out of the finished product. And of course this introduces another failure mode into the complex system that is the production chain. Yield of the finished product is affected by the yield of all subproducts that go into it. So if QC misses some faulty componentry, then in the next step a good component is attached to the bad, and the whole assembly is potentially lost.

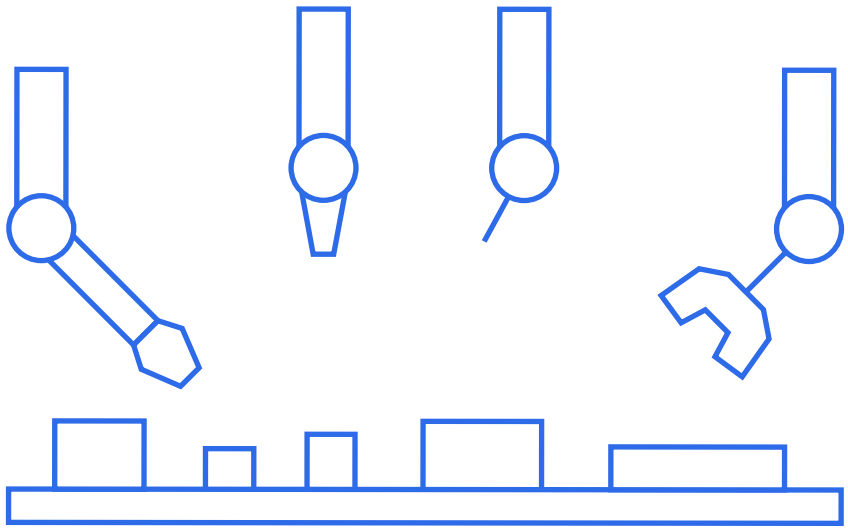
Inspection, Quality Control
Data-gathering is a major part of almost any processing line. Information about the health of a production line is gathered through measurement and inspection of intermediate and final parts. And then that information is used to tweak system parameters to improve yield or quality, or any number of other parameters. This part of the process is a great place for automation, with camera hardware and machine vision algorithms becoming ubiquitous, though careful customization and integration is usually required for setup. And even something as simple as the lighting in the area of the camera can make or break one of these setups.

Will sunlight stream through a window during a certain time of day and illuminate the part in a way that throws off the camera? What if that only happens during a certain time of the year? Or will a human passing by the machine cast a shadow on the workpiece from a particular overhead bulb? Many considerations need to be made to how consistently a part can be illuminated, such that the camera records a meaningful image and can deliver accurate feedback every time. But once lighting and illumination is worked out, and the algorithms fine-tuned, that camera system can function 24 hours a day, for years on end, catching details in milliseconds that the human eye would not be able to detect at all.

Material Uniformity

When designing and running automation equipment, uniformity is king. If the material being handled is all the same size, shape, weight, texture, firmness, you-name-it, then it's much easier to design a machine that can pick up, convey, separate, assemble, inspect or perform any number of other repetitive operations on it. If it's easier to design a system then it's probably easier to build and maintain it also, and this forever impacts the COGS and thus the price of the output product.

So in this modern age many more parameters need to be optimized for than just speed, cost, yield, or throughput. Of course, the holy grail is optimizing for all of these parameters, but the truth is that **engineering is basically the art of managing tradeoffs**. For this reason, handling irregular materials or custom shapes will always be more expensive, with machine complexity needing to scale up dramatically to handle the irregularities of the material.



But machine design is not the only way to improve an automated process. Much can be gained from a more controlled, repeatable, predictable input material. This is true in every industry from textile threads, to lab reagents, to ears of corn. Great amounts of engineering effort and investment goes into improving intermediate materials. Perhaps just as much effort goes into the materials as goes into the equipment designed to handle and process it. This doesn't necessarily mean the materials themselves need to be of higher quality; as long as an operator or machine can predict and calibrate for the actual properties of the material, then the automation equipment can be configured to run with it. And the easier it is to configure a machine to handle a certain material, then the simpler and more robust the machine and the process line can be.

It's also worth pointing out that the end product of just about any process quickly becomes the input material to someone else's process. The more uniform the widget that comes off of Company A's production line, the easier of a time the customer will have incorporating that widget into their own automated processes.

Dealing with non-Homogeneity

Of course, machines can be built to handle even the most irregular of shapes and materials, but the complexity of such a machine often goes up by 2x or more for every extra degree of variability that it must handle. Consider that for every sensor that exists in the world, there is a material that was meant to be sensed. From moisture, temperature, thickness, reflectivity, weight, porosity, to any number of other physical properties, there are sensors available (for a price) to measure it. And instrumentation designers will put as many sensors as are needed into a system to give it the intelligence it needs to perform its function.

Imagine the metal foil that arrives at a battery plant in giant rolls, ready to be cut and folded into batteries. If that foil varies in thickness across the roll, then a sensor will need to be placed in the system to measure the thickness of the foil as it is pulled into the machinery, and take some action to compensate. That sensor adds cost, and now exists as a point of failure on the production chain. If that sensor fails, the whole system goes down until it is fixed. The way around this is by making sure that the metal foil is guaranteed to be of very uniform thickness before it ever leaves its supplier. In this way the thickness sensor can be skipped altogether, saving cost and increasing the reliability of the battery production line by having one less failure mode; one less chain link to break.

In commercial-scale production, where volume is high and prices are low, it's very important to keep equipment costs down and robustness/reliability up. The equipment has to work as expected or it won't get used. For this reason there will always be a strong push to reduce the number of sensors or actuators to the smallest number possible. This reduction in complexity over time is one of the prime indicators of the maturity of a technology.

Operation Mode

To set us up for discussing automation across industries in later articles, I also want to outline the different operation modes of an autonomous system, corresponding to how much feedback data a system receives from different points in its process, and how much of a role humans directly play in carrying out the process.

Open-Loop
An open loop is not a loop. Put simply, commands and materials go in, but the machine has no awareness of what comes out. There is no feedback mechanism, or no way for inspection data to loop back into the process to improve any of the steps. This might also be called dead-reckoning, in which the machine does X for Y seconds and then goes on to the next step regardless of the outcome of the previous step; or really without even knowing if the previous step happened or finished yet. No system being monitored by a human is ever truly open-loop, since we are always using our onboard sensors for taking in sight, hearing, and pressure/vibration information.

Closed-Loop
Closed-loop operation describes when there is a feedback mechanism or data pathway for information about the final product to loop back into the process, so the process can be iteratively improved or self-corrected. Most automated processes would be run this way, where the operator or designer tunes the final product, rather than the instrument itself. Well designed machines can run fully autonomously in this mode, often using machine learning or AI principles to adjust itself to give some desired outcome.

Supervisory Control
Also known as **Human-in-the-Loop**, this describes a system that uses automated action to control most of the details of a process, with a human taking over control at certain critical steps, or making decisions at critical junctures. The human operator controls the task, rather than controlling the specific individual actuators of a system. It is often characterized by language-like interfacing, or menu-like interfacing

with a computer handling the mechanical actions of a machine system. This could be performed locally with the operator standing at a terminal on the machine; or just as easily with a remote operator, taking in remote sensor data and perhaps camera feed.

A useful variation on this is described as **telepresence**, or the ability for a remote operator to call in, monitor, and adjust the functions of an automated system. The operator might tweak some system parameters to keep the machine humming along, or perhaps even take over direct control to correct some issue like a stuck part, or maybe to bypass a problematic sensor until it can be checked in person. This is perhaps the most valuable form of human-machine collaboration for periods such as this Great Pause. This would enable machinery to run day and night, only calling out for human assistance by alarm, warning lights, or even SMS text to the operator or technician if a problem is detected by one of its many sensors.

Direct Control

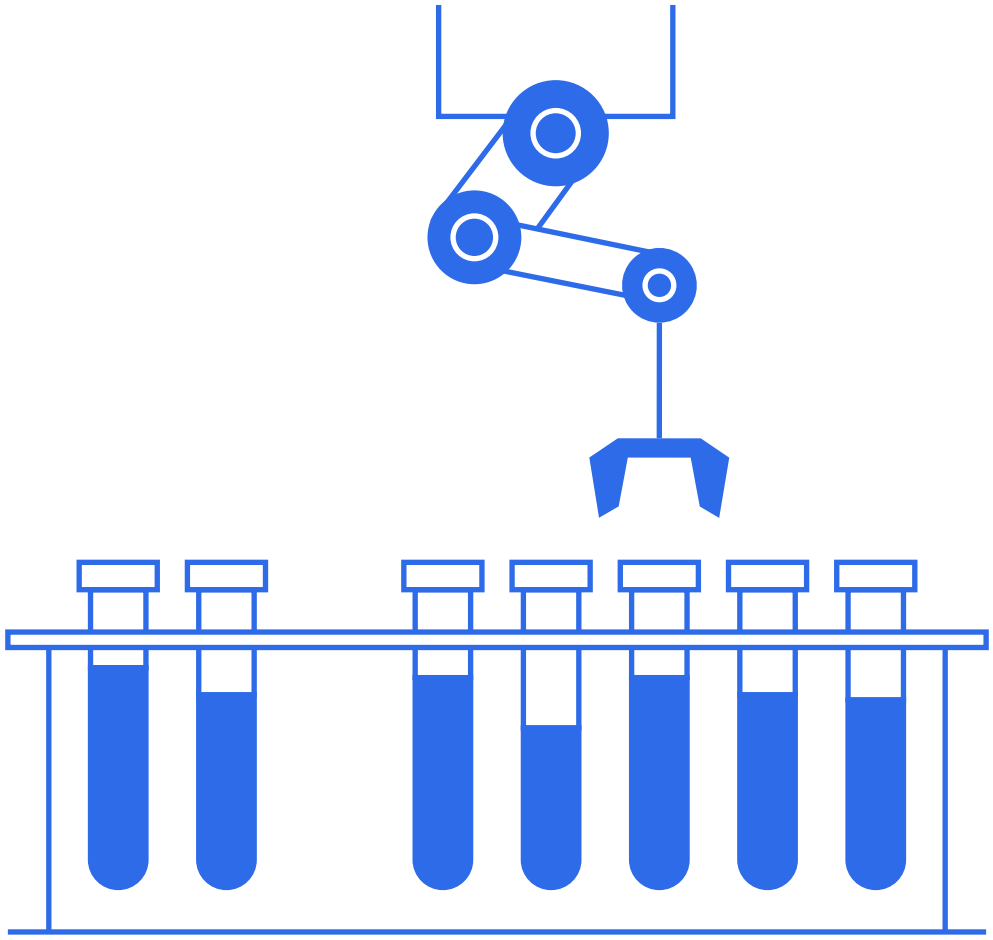
An extreme form of Human-in-the-loop would be when a human is indeed controlling every motion that a machine undertakes. This would be a case where the machine does nothing without direct command by the human operator. An example of this would be a surgical robot; with cameras and sensors feeding information to a remote human doctor, who then commands each motion of the robotic arm by manipulating the buttons and interfaces on the surgeon-side terminal. Maybe the doctor has a joystick of sorts, or perhaps even a glove that converts the motions of the doctor's hands into movement of motors on the robotic arm. This type of operation could also be done with language-like commands, but this would be impractical in most applications requiring real-time control.

Automation in Laboratory and Healthcare

In Healthcare

When you hear the word *automation* you might first think of a factory full of robotic arms tirelessly toiling away on an assembly line. But there are more direct ways that automation can safeguard our lives, such as the Boston Dynamics robotics toolkit for telemedicine, that can remotely collect vitals data and triage patients without exposing medical staff. Or bedside devices that can directly intervene in our healthcare, such as infusion pumps used to deliver medications intravenously using programmed dosing schedules and alarm states. And a Rutgers-led team recently built a robot that sampled blood as well or better than a human: "The device includes an ultrasound image-guided robot that draws blood from veins. A fully integrated device,

which includes a module that handles samples and a centrifuge-based blood analyzer, could be used at bedsides and in ambulances, emergency rooms, clinics, doctors' offices and hospitals." (Science Daily) And perhaps a bit further down the road will be robots working alongside healthcare professionals, providing a third hand when needed.



In the Lab

And then there are more subtle ways that automation shapes our daily lives, namely through the research being conducted in genetics and drug discovery. In truth, the field of genetics would not exist in its current form without laboratory automation, since the vast repetition required for sequencing and synthesis would be nearly

impossible if performed by hand. And drug screening and discovery has been accelerated by many orders of magnitude from the early days of pharma; from testing 10–100 compounds per day in the 1980s, to well over 1–10 million compounds per day today with the help of specialized automation equipment. Bringing more automation into the wet lab environment is not new, and has been a fruitful pursuit for decades now. By wet lab I am referring to chemistry or life science lab spaces in which any number of physical processes are carried out, but commonly involving the moving, mixing and measuring of biological specimens, liquids, and chemicals. There are dozens of operations involved in most protocols, such as pipetting, mixing, dividing, and measuring, many of which are tedious, repetitive, and exacting. And while any good protocol is designed to reduce the risk of biological contamination and skin exposure, a protocol is only as good as the attention span of the personnel performing it. Further, precise measurement of reagents is almost always part of the job, and yet humans are prone to error, especially when a job is tedious and boring, or performed with urgency as is all too common in startups and critical testing laboratories. Imagine the pace of the labs today trying to process tens of thousands of COVID tests, with lives potentially hanging in the balance.

This is the perfect environment and use-case for automated equipment. Robots can run 24 hours a day, pipetting a precise amount of liquid a million times in a row with minimal variability, repeating the same protocol dozens of times, or jumping back and forth between multiple protocols without skipping steps or getting any of the barcoded samples mixed up. Consider something as fundamental as the labelling that is needed to keep 10,000 patient samples separated and anonymous, when using a human-readable label format. I don't mean to suggest that trained technicians and scientists are likely to mix up a vessel of reagents very often, but hand-written labels are common and transcription/data-entry errors still happen, especially when fatigue sets in. There are some jobs that machines are just better suited for.

In fact, there is a vast array of automated equipment in use today in labs across the globe. These usually exist as a benchtop unit, perhaps the size of a microwave, that a human delivers a rack of tubes, or a microwell plate for a single action to occur on each of the vessels. The boosts to productivity and reduction in human error in particular steps in the process are easily recognized, with particular pieces of equipment selling for prices anywhere from $25k USD for a simple operation such as capping/-decapping tubes, to analyzers that sell for $5mm USD for measuring what is happening inside of those vials using light, or any number of other physical measurements.

Why Lab Automation is Important to COVID Testing:

We must apply new insights from our current pandemic-driven labor lockdown to create and fund the most crucial pieces of automation equipment to harden our labs against future disruptions.

"Today much of the testing is done manually, with the very real risk of exposing lab technicians to the virus. Sadly, two people in a Tel Aviv lab were recently diagnosed as positive for Covid-19 after coming in contact with test kit fluid….. By automating the lab testing process, work can be done 24 hours a day and 7 days a week, dramatically increasing the volume of tests per day." (Bright Machines)

Bright Machines has an automated microfactory that is doing COVID testing in an Israeli hospital (Bright Machine Press Release). Per CNET, "Bright Machines is also working with testing manufacturer Diagnostics for the Real World to automate the assembly of HIV test cartridges for its platform. With a microfactory, the diagnostics company plans to speed up cartridge assembly time from two minutes to 20 seconds per unit, and increase overall output from 100,000 units a year to 1 million units a year, according to a blog post."

And here in the San Francisco Bay Area: “The [UC Berkeley IGI] lab will run testing based on a process approved by the Food and Drug Administration, but with higher throughput than many commercial labs, some of which still must run samples manually, one at a time. The high-throughput machines, some sourced from campus research labs, can test more than 300 samples at once and provide the diagnostic result in less than four hours from receipt of patient swabs. Using robotics and a streamlined process, the IGI pop-up lab will soon perform 1,000 tests daily, with the ability to ramp up to 3,000 tests per day if necessary.”

Instruments and Workcells

While a single step in a protocol may be automated by a benchtop instrument, full protocols can be automated through larger units called **workcells**, which use some conveyance mechanism such as a robotic arm to tie together multiple instruments. While the workcell does increase the complexity of the system by adding the arm and the scripting code, it can be expected to improve quality, speed and cost of the process, while making for a much more compact laboratory layout.

There are many providers of workcells in the medical/testing space, including Hudson Robotics, PAA Automation, Transcriptic, ThermoFisher, BD Kiestra and Hologic.

Workcells range in complexity, cost, and versatility. A “simple” example of a workcell is shown above, adding a 3rd party robotic arm to a cluster of existing legacy devices with the robotic arm taking the place of the human technician that would ordinarily be moving samples between devices and pushing buttons to activate. These will be the most versatile, since a workcell like this can be assembled from any number of instruments used to string together process steps such as uncapping/recapping test tubes, populating assays, reading sample barcodes, sample loading, adding reagents to an assay, incubating or storing assays and analyzing the results of the assay. All or parts of this process can be automated through different tools, usually all run from a central scripting computer that is moving the arm and interfacing with APIs running on each of the individual instruments.

In many ways this integration is the most difficult part of the process, getting the central computer to be able to talk to and handle the idiosyncrasies of each of the individual tools, each with their own processors and firmware. And the mechanical tolerances of the individual devices cannot be overlooked.

Something as simple as placing a rack of tubes on a tray is very easy for the human hand, but a robotic gripper with minimal haptic feedback can run into any number of tiny mechanical features that might cause the rack to catch, be dropped, or left askew when it needs to be flat and squared to enter the machine properly. Device makers need to take these features into account during initial design, future-proofing their equipment for increasing automated handling, and for customers that are looking to buy manually operated devices today that can be incorporated into automated workflows down the road.

For more mature processes, companies may integrate all of the various functions into a single platform device. This increased level of integration between devices/functions can be expected to deliver higher reliability, with a higher initial price tag, and very little ability to customize.

Integration and Validation

It is my belief that as workcells become more affordable and capable they will change the nature of lab work forever. And the more integration-friendly a particular piece of equipment is, the more likely it will get incorporated into the production workflows of tomorrow. Once a protocol and workflow is established, a workcell will be designed to perform it repetitively. And once the workflow is validated the workcell operator will be loath to change anything about it, ever. The validation process for a major production line might take months of painstaking testing, monitoring, and tweaking. For this reason, it can sometimes be critical to be the first to market with a new piece of equipment, to be the supplier that they go into validation testing with.

This drawn-out validation process also makes strong pilot partnerships very valuable, giving a friendly testbed to work out the kinks, and a toehold for first customers and promoters. A startup entering the market with a new piece of lab automation equipment should focus on absolutely nailing the execution on their pilot programs, and then should ensure that their firmware API is rock solid and dependable. The workcell is basically a programmed chain of processes, and any failure on that chain can disrupt and ruin the whole run; with consequences of lost patient samples, contamination, or worse. The piece of equipment on that chain that causes the most errors and headaches is the most likely to be eyed for permanent replacement, with potential reputation and brand damage.

My advice: build and invest in automation equipment that is workcell-ready, with rock solid firmware and APIs that are a pleasure to interface with. For designers, talk to customers and design for their needs, and make sure you are compatible with the major workcell-integration software packages. For investors, talk to the pilot customers and ask them what their experience has been integrating the startup's product offering into their workflows. Customer success is very important here, since all of these tasks could be performed by hand, the new machine needs to provide tangible streamlining and benefit over manual work to justify the cost and upkeep of the machinery.

Consumables

The consumables that are used by these automated machines can be bigger business than the machines themselves. In fact consumables often have upwards of 80% margin, using business models analogous to selling printer ink. These days most consumables are designed with automated handling techniques in mind, with subtle mechanical features that make them easier for robotic grippers to align with and grasp more reliably.

Microwell Plates

The test vessel of choice in most labs these days is the microtiter plate, or microwell plate, also referred to as a microplate, multiwell plate, or simply as a plate. These microplates are typically made from injection-molded plastics chosen for the particular application, and are considered single-use consumables. They have a standard outer formfactor of 127.71 mm x 85.43mm (5.03 in x 3.36in), which fits nicely in the human hand, and many robotic arms and grippers are built to handle this exact size. Each plate is subdivided into a multitude of individual wells, each of which can serve as a reaction vessel or incubation chamber for a different experimental mix of ingredients or biological components. The most common sizes are the

- 96 well microplate, with wells about the diameter of a pencil
- 384 well plate
- 1536 well plate, holding just 8.75uL of liquid each
- Less common, but still available are 3456 and even 9600 well plates.

These plates are important to understand as they make up the backbone of many high throughput lab workflows. Custom microplates can be made with specialized microfluidics, materials, coatings, or well shapes to better suit the instruments they are used on. These proprietary plates can be a lucrative source of revenue if they are compatible with the rest of the workflow and become the new standard, but conversely

they can also lead to a device being pigeonholed in function, relegated to a corner of the lab and getting little use because of the need to stock inconvenient consumables.

Throughput

Capacity Improvements and History

High Throughput Screening (HTS) was originally used in drug discovery because of the need to perform myriad tests on compounds to determine the potential efficacy of treatments. According to a 2015 National Institutes of Health paper, "A decade ago, HTS operations using infectious pathogens were infrequent." In reference to the HTS process, they state: "Early infectious disease HTS efforts were directly adapted from manual antiviral or antimicrobial assay formats and conducted in 96-well microplates by automating the low-throughput steps. For example, manual procedures specified that eukaryotic cells were dispensed to the assay plates, then incubated overnight, and allowed to form an attached monolayer before the addition of test compounds. After the addition of compounds, the assay plates were transported into the BSC (biological safety cabinets) for the addition of virus. This process involved moving each assay plate to and from the incubator multiple times, which altered plate temperature and media pH and contributed to increased assay variability. In addition, it provided multiple opportunities for plate mishandling (e.g., to accidentally drop plates), which contributed to reduced biosafety….. **Due to these factors, throughput using this process was limited to less than 50 plates (~4,000 compounds) per day**…. The process improved when reagents were developed for an add and read endpoint and the large liquid handler was replaced with a small-footprint, portable noncontact dispenser … The next process improvement came by miniaturizing cell-based assays from a 96- to 384-well microplate, which simultaneously reduced reagent use and increased throughput…. **[This] streamlined the process for infectious pathogen assays to the point where batches of approximately one hundred 384-well microplates (32,000 compounds/day) could be prepared with minimal plate manipulations and increased assay reliability and robustness.**

A 2011 LabManager.com article provides the following history of testing throughput capacity improvements — a lot of this applies to drug discovery and not directly to pathogen testing. At a high level, we're talking about going from a lab being able to screen 10–100 compounds a week at the start of the 1980s to over 1mm per day by 2005:

"Until the 1980s, the number of compounds that could be screened by a single facility in a week was between 10 and 100.

In 1986, Pfizer was involved in natural products screening by substituting fermentation broths with dimethyl sulfoxide solutions of synthetic compounds, using 96-well plates and reduced assay volumes of 50–100µl. Starting at 800 compounds each week, the process reached a steady state of 7200 compounds per week by 1989.

By 1992, technology had advanced enough that thousands of compounds could now be screened by a single facility in a week. By this time, Pfizer was using HTS to produce approximately 40 percent of its 'hits' in its Discovery portfolio.

By 1994, tens of thousands of compounds could be screened per week, but 384-well plates were still extremely rare.

The 1994 International Forum on Advances in Screening Technologies and Data Management saw the first mention of the term 'Ultra-High-Throughput Screening' in a presentation by Harry Stylli entitled, 'An Integrated Approach to High-Throughput Screening'.

By 1996, uHTS was considered a realistic goal, and 384-well plates were being used in proof-of-principle applications. Around this time, thousands of compounds could be screened in a day in a single lab.

In 1997, LJL Biosystems, Inc. raised the bar in the number of compounds that could be screened in a single day with its first high-throughput screening system, ANALYST. This instrument was capable of throughputs of approximately 70,000 assays per day, exceeding traditional throughput averages by up to five to ten times.

By 1998, tens of thousands of compounds could be screened per day, and genomic targets were a reality. By this time, 384-well plates were widely used, and 1536- well plates were being used in proof-of-principle testing.

In 2000, Aurora Biosciences completed development of an ultra-high throughput screening system for Merck. This platform combined compound management, plate replication, assay preparation, hit identification, selection and re-tests of the hits, fluorescence detection, and data analysis into one fully-integrated and automated system that enabled the performance of miniaturized assays with a ten-fold increase in efficiency over conventional high throughput screening methods.

In 2005, high-throughput screening reached new levels of efficiency when RTS Life Science began selling the Symphony ultra-high-throughput screening system developed in conjunction with Novartis to European customers. The Symphony system was

conceived as a multi-lane robot system combining local compound storage, reformatting, assay plate creation and screening and was designed for use in laboratories needing to screen in excess of 1,000,000 compounds per day.

In 2009, BioTrove announced the launch of the RapidFire 300 system for high-throughput screening of in vitro ADME assays, enabling researchers to perform a wide range of assays with 24-hour, unattended operation. The RapidFire system streamlined drug discovery workflow, significantly decreasing the processing time compared to conventional MS-based technologies and helping to eliminate bottlenecks in drug discovery while providing accurate results for data-driven decision making."

Worth Noting:
"Being able to process tens of thousands of tests per day is great on paper, but it means nothing if one ingredient you need to make that happen is also required by every other testing lab in the country." (TechCrunch)
Clinical Laboratory Improvement Amendments (CLIA) Labs need to be CLIA certified to test patient samples. This certification applies to scientists, equipment, lab space and quality control procedures. It's not enough to have the ability to do testing with high-throughput machines; it must also be done with CLIA certifications.

Conclusion

The market for lab automation equipment is blossoming with no signs of slowing down, following the general trend of the life science industry at large. Since the needs and methods of the life science sector are continuing to rapidly evolve there will be a continual need for new instruments and new automation. It's worth noting that large companies like Thermo Fisher Scientific, Siemens, and Beckman Coulter have massive catalogs of automation devices under their brand; and this is because they very actively seek and acquire startups that gain traction with a new device that fills an important market need. This consolidation can be a good thing for the industry, as the process of bringing these devices under one umbrella often makes for smoother software and workflow integration between devices under the same brand.

And then there are more radical approaches to addressing this market, such as the Emerald Cloud Lab, where a customer ships samples to their highly automated facility and then runs experiments entirely remotely. With solutions like this it is becoming realistic to imagine a laboratory environment requiring very little on-site human

supervision, with most of the staff working remotely to design and monitor experiments using cameras and telepresence technologies. In this way we can safeguard our most critical life science capabilities in even the most extreme quarantine conditions, and create an environment of collaboration and telepresence that can span the globe in times of turmoil.

Startups
Emerald Cloud Lab
Transcriptic
Kebotix
Bright Machines
Color
Randox Laboratories

Major Equipment Suppliers
Thermo Fisher Scientific, Inc.
Tecan Group Ltd.
Siemens Healthcare (Subsidiary of Siemens AG)
Roche Holding AG
Qiagen N.V.
Perkinelmer, Inc.
Hamilton Robotics, Inc.
Beckman Coulter, Inc.
Biomérieux SA.
Agilent Technologies