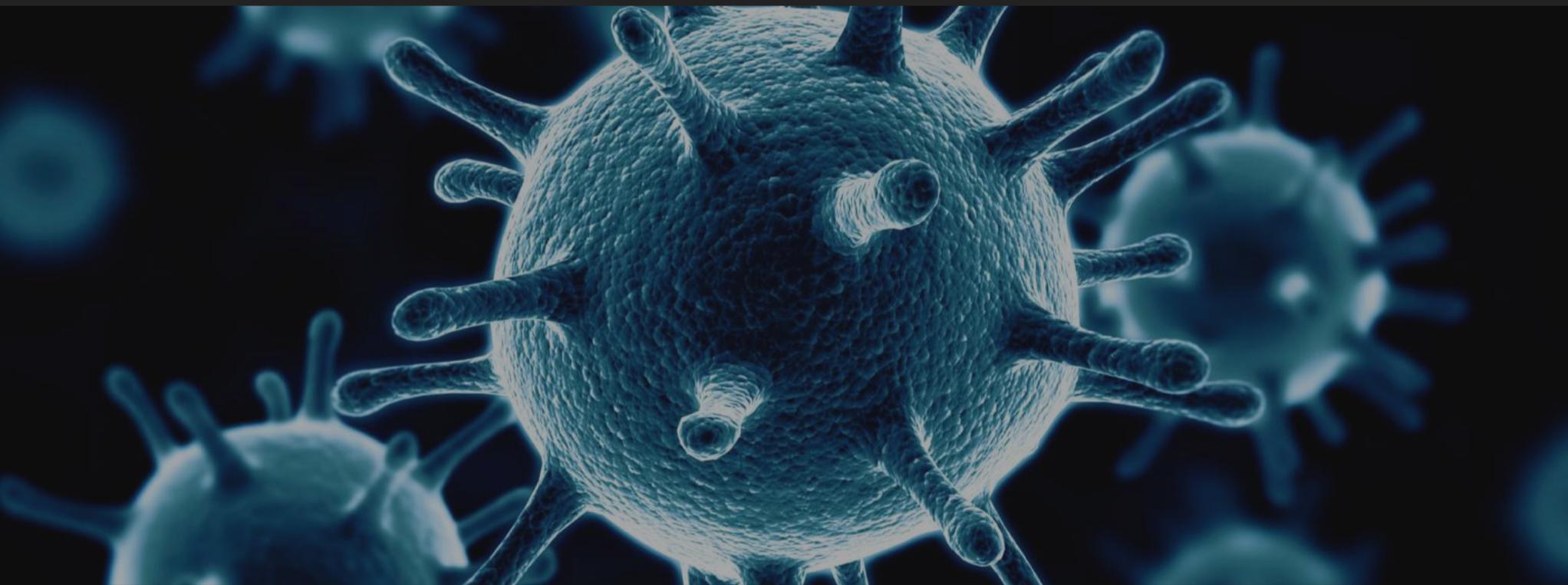


COVID-19

PHARMACEUTICAL MANUFACTURING EMERGENCY SCALE-UP



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EXECUTIVE SUMMARY

We anticipate that a COVID-19 treatment or vaccine will be greenlit for production by the US government in the near term. The manufacturing scale-up required to produce and distribute vast quantities of product will be unlike any previous pharmaceutical manufacturing process effort in history. This document outlines what a coordinated industry wide biotech manufacturing response at unprecedented speed and scale could be. We present four actionable scenarios to frame how we as an industry can adapt and evolve to bring to market a vaccine much faster than currently anticipated or allowed for under the current default manufacturing and validation frameworks.

These scenarios are rooted in the spirit of uncovering and eliminating unnecessary steps to streamline the manufacturing response. The required response is an undertaking too large for any one company to solve in isolation using their specific and particular processes. We advocate for a highly coordinated, centralized and standardized government led response to bring about the most efficacious results in the shortest amount of time.

The task at hand is no small feat. Herein, we set out to excite the industry and think about the possibilities and opportunities ahead of us. We firmly believe that as a united front, in collaboration, we can rise to this challenge with bold vision. It is of paramount importance to assess the parameters of this problem and deploy a standardized process for continuous manufacturing. This document is a call to action and a call for collaboration to that effect.

ABOUT SKELLIG

Skellig as a company has the ability to bring the right people together to get an optimal pharmaceutical manufacturing operation up and running. Our core capability is automation design and development for the pharmaceutical industry. We view automation as the language of a pharmaceutical facility. We have the ability to bring the right people from the right disciplines to the table and get people working together with structure and clarity towards the end goal.

EXECUTIVE SUMMARY

CONTEXT

- The unprecedented and escalating COVID-19 scenario requires an immediate examination of the default pharmaceutical manufacturing processes governing the production of biotech products.
- The rapid implementation of a collaborative and streamlined industry response will provide the ability to distribute and scale production, improve facility retrofits and batch production timelines, and simplify regulatory approval.

PROBLEM

- As a nation we are ill prepared to meet the demand for product needed today.
- The regulatory framework governing the manufacture and validation of biotech products is cumbersome and slow. This is currently causing, and will continue to cause, unnecessary delays in the the scale up of production and delivery.
- Immediate reform and elimination of unnecessary but commonly employed approval processes is needed to save lives.

RECOMMENDED APPROACH

- The Biotech / Pharma Industry needs to respond with a speed and scale that our industry is not (yet) familiar with...with bold vision we should model the approach on best practices from different business sectors...

AMAZON: lean management methodology, streamlined logistics and delivery

LEGO: design modular components to integrate systems

McDONALDS: standardized process to control centrally and deploy locally

APPLE: deny limitations and produce the impossible

- It is essential to provide clarity on how all of us in pharmaceutical manufacturing, at all levels within the industry can safely share the effort.
- We need industry-wide appropriation of the most advanced information sharing methodologies to drive clarity into the design. A shared, collective intelligence will radically improve the speed at which things happen.
- When looking to existing facilities for an emergency scale-up of pharmaceutical manufacturing, a centralized effort (top-down approach) must be met with a localized attempt (bottom-up approach) to assess the existing facilities.

EXECUTIVE SUMMARY

SOLUTION

- Prioritize the rapid retrofit of existing facilities (maximum of 3 months) over the build out of new facilities (minimum of 1 year)
- Identify existing facilities with a high degree of equipment compatibility for a distributed production deployment.
- Temporarily replace and standardize all local control systems to a singular control systems design providing for the pre-validation and qualification of the majority of the system.
- Centralize as many steps as possible to allow a large number of sites to begin operating in a very consistent manner, in the shortest time possible.
- In parallel to a retrofit effort, or as an alternative scenario, we should initiate the buildout of new facilities with OEM (original equipment manufacturer) equipment utilizing a near identical control system and roll out approach as the retrofit scenario to meet the sustained demand for product beyond the immediate emergency scale up.

UNANSWERED QUESTIONS

- 1.** How long will (retrofitted) facilities be used to produce the treatment (and how long will it take for these facilities to be able to return to business as usual afterward)?
- 2.** In terms of considering equipment trains, is the existing patient population sufficiently served either by other equipment trains or by stockpiles so that a particular train may be taken down safely to support COVID-19?

INTRODUCTION

EMERGENCY SCALE-UP

In an emergency like the global COVID-19 outbreak, it's essential to provide clarity on how all of us in pharmaceutical manufacturing, at all levels within the industry can safely do our part. When looking to existing facilities for an emergency scale-up of pharmaceutical manufacturing, a centralized effort (top-down approach) must be met with a localized attempt (bottom-up approach) to assess the existing facilities.

This document holds an early version of ideas that we believe can aid in the challenge of manufacturing a pharmaceutical product more rapidly at scale than ever before.

These ideas need to be shared broadly, in the hopes of adding rigor to a plan in the fastest way possible. They may also inspire a better approach than proposed here. We aim to contribute to a constructive and open conversation on the path forward and to inform and expand the tactical choices at our leaders' disposal. They must be empowered with the best strategies to overcome this immense task.

We propose four scenarios. All four can be considered separate, or combined in some way, depending on the final variables of what exactly needs to be produced at scale.

This document is written without a set of requirements for manufacturers and with a mAb style product (monoclonal antibody) in mind.

After reading this white paper, two main questions remain open that will call for a detailed response:

1. How long will (retrofitted) facilities be used to produce the treatment (and how long will it take for these facilities to be able to return to business as usual afterward)?
2. In terms of considering equipment trains, is the existing patient population sufficiently served either by other equipment trains or by stockpiles so that a particular train may be taken down safely to support COVID-19?

In an emergency scale-up, the plan must adequately address the need to minimize disruption to the existing process, as well as minimize the risk of misusing intellectual property.

KEY POINTS

- Once a pharmaceutical product is identified for COVID-19, we must act swiftly and boldly. The exponential effects of this disease are frightening. It is of critical, global importance that we manufacture a treatment at a speed and scale to match the problem. Any time reduction will undoubtedly save lives. With a possible death rate in the millions, there is no further justification required.
- We write this white paper as a process automation guide to emergency manufacturing for COVID-19. It serves as a guide for leadership with scenarios to explore solving the problem as effectively and quickly as possible.
- After reading this white paper, the reader will have a sense of what scale of response is possible. A different plan may be needed if the identified treatment doesn't fit any of our proposed scenarios.

FRAMING A CENTRALIZED APPROACH

WHY NOT BUILD NEW FACILITIES?

Existing facilities are intended to manufacture a single product. They are rarely described as multi-product facilities. And even for those that are, the switch-over process can take months.

Similarly, the design and build of new facilities is typically a year-long process, at best.

However, the equipment we would need to manufacture a treatment is most likely already widely available in (roughly) the required configuration. A traditional retrofit of a facility would take months. Therefore, the central question should be: what exactly would it take to make something of high quality, faster than ever before, and on a global scale?

As an industry, we have accepted the slow speed of our process set up to help demonstrate to the FDA and equivalent regulatory bodies that we produce a product as described—resulting in a lot of paperwork to provide traceability.

We know improvement is possible, but it has always seemed too risky to consider change. Although people at the implementation levels are often frustrated, frustration alone hasn't been enough to inspire a break from the dogmas of the current process.

These ideas need to be shared broadly, in the hopes of adding rigor to a plan in the fastest way possible. They may also inspire a better approach than proposed here.

Just as the FDA and equivalent regulatory bodies partner with drug discovery efforts across the industry, many current rules and regulations in this area are now up for debate. It's become clear that some practices aren't imperative, because of the global scale of the problem.

Industries can change the norm. Amazon changed what we consider an acceptable time to wait for a package to be delivered.

A two-week delivery was the norm 20 years ago. Now, a delivery takes two days for most people, one day for many, and some enjoy same-day delivery. Collectively we're aware that Amazon is working toward one-hour delivery. And nobody bats an eye.

FRAMING A CENTRALIZED APPROACH

WHY NOT BUILD NEW FACILITIES?

In response to the current crises, we need to change the norm of our industry. We need to 'Amazon' the pharmaceutical manufacturing process.

In doing so, important points to consider include:

- We can't compromise the quality of the product in any way.
- We need to look at once at what we do and how we do it.
- We must think on a global scale.
- We must start sharing ideas widely and aggregate the best ones to the top.
- We must look at models from other industries and areas of life and use what's applicable in this situation.
- Only aiming to speed up the existing waterfall design (waterfall meaning: define the process, then start the automation, then validate) and implementation approach will result in needlessly subpar results and will take too long.

As humanity, we are now facing a global challenge. As an industry, we are facing the opportunity to drastically change our approach, to pioneer speed and collaboration and rise to the occasion prodigiously.

WHAT'S REQUIRED?

- Focus on the end-goal. Apply a lean methodology of process principles. Keep only those process principles that are necessary. Discard the rest.
- This will require smaller, but highly capable teams, with people clearing roadblocks around them, such as typical corporate management roadblocks, raw material roadblocks, talent roadblocks, intellectual property roadblocks, et cetera.
- Collaboration. COVID-19 is the competition. Not Pharma company A or Pharma company B.
- A realization that the patient is waiting. Lives are at stake. Now. The new wave of thinkers in biotech is astutely aware of this, and it has fueled creative and out-of-the-box approaches to solutions. Established pharmaceutical companies need to adopt the same awareness and open-mindedness immediately.
- We need industry-wide appropriation of the most advanced information sharing methodologies to drive clarity into the design. A shared, collective intelligence will radically improve the speed at which things happen.

Easier said than done? Yes.

Biotech / Pharma needs to respond with a speed and scale that the industry is not (yet) familiar with. However, other sectors are. Pulling together, we can model our industry to best practices from different sectors. The four scenario's that we will describe, do precisely that.

FRAMING A CENTRALIZED APPROACH

WHO SHOULD WE MODEL?

Looking at best practices from a vast array of industries, here are four that we believe we should model in overcoming this crisis with a bold vision.

AMAZON

In line with Skunk Works' approach, Jeff Bezos famously instituted two-pizza teams (meaning that the team is too big if you need more than two pizzas to feed them).

But there are more reasons to look to Amazon for inspiration on applying lean thinking to a situation.

Amazon simplified and reduced the logistical moving parts of order fulfillment and delivery. The pharmaceutical industry could likewise simplify and streamline the overly complicated design, quality, and validation approach.

Our industry's goal is always to create a safe, consistent product. That is not up for debate. Lean thinking is not a way of cutting corners, but it could benefit how we approach change to the design and qualification of facilities.

For a large scale COVID-19 response, we should centralize design, implementation, and qualification as much as possible. Thus, limiting the variance in approaches across facilities and being able to fast track roll-out.

Biotech / Pharma needs to respond with a speed and scale that the industry is not (yet) familiar with. We can model our industry on best practices from different business sectors.

LEGO

An industry leader in many ways, Lego always offers good inspiration. The company sources information, feedback, and design from the people most passionately involved with their product: their fans. This offers Lego the opportunity to mine immense amounts of data on the usability, effectiveness, appreciation, wants, and needs for their product.

They're also famous for quick prototyping: they throw a product into the market and rework it based on the feedback of consumers rather than from the engineers (sourcing).

For Pharma however, the most interesting aspect is the core product itself: bricks. A formulaic product that one can mix and match to build anything. The bricks are like equipment that's quick and easy to combine and use in different ways, building and re-building entire constructions with a vast array of possibilities. Modular and extremely versatile, these bricks are the perfect example of swapping equipment around to get facilities up and running in record time.

FRAMING A CENTRALIZED APPROACH

WHO SHOULD WE MODEL?

McDONALD'S

For large scale responses like COVID-19, it is essential to look at new models that represent how to produce something consistently at scale. For that, McDonald's provides an example of how to have centrally controlled procedures and methods, coupled with consistent equipment deployed locally. Pharmaceutical companies have compatible equipment but are locally managed rather than centrally. This dilutes company resources and establishes different ways of getting to the same endpoint. It has worked, only because we have never needed a fast, global response as we need now.

For pharmaceutical companies, COVID-19 should represent a fresh opportunity to focus on what's essential: a consistent product that is widely and readily available. A consistent product is not a problem, how long it takes, and how much it costs companies to get there is. Following McDonald's method, we believe it's advantageous to invest early in a very robust design that could then be copied to achieve scale. Applying this kind of standardization in a COVID-19 response would bring incredible long-term advantages for pharmaceutical companies.

APPLE

And finally, for large scale responses like COVID-19, it is essential to look to Apple for inspiration. The team that developed the first Macintosh computer defied what was theoretically possible at the time. Apple's team approach was special for many reasons but above all they built something they would want to use themselves. A working continuous manufacturing design for a treatment that is probably going to be developed for traditional batch right now is a very exciting prospect.

FOUR SCENARIOS

SCENARIO 1: CENTRAL MANAGEMENT OF A GLOBAL MANUFACTURING RESPONSE

THE McDONALD'S METHOD

STEP 1

Mobilize a central design team to implement process development, design, and implementation. A central team of process engineers must lay out the steps needed to make the product. The automation engineers need to write the control system code simultaneously.

This effort centers around P&IDs (Piping & Instrumentation Diagram), fully functional automation throughout the project. While we must carefully document everything throughout, the documentation must not be the focus. It should only matter at the end, as part of delivering a thorough qualification package.

We must centrally establish and apply standard operating procedures to facilitate a bypass of a facility's existing quality management in favor of centralized quality management. We would develop these along with all other aspects of the design.

STEP 2

In parallel to the central effort that represents a top-down approach, a localized bottom-up approach is equally important. As the process and specific site scenarios become clear to both the central and local teams, a decision can be made for each equipment train on where to draw the line of central and local merging. Where the two meet defines the 'goldilocks zone.'

A localized team, in coordination with the central group, must visit and evaluate existing facilities for a possible equipment train match. The ideal scenario is an equipment train match along with a control system match.

The centrally qualified design would be more likely to produce a higher quality product in less time and require less interpretation at various sites.

STEP 3

Once the emergency response is no longer required, the field service team will revert to the original and unchanged control system, allowing the site to rapidly accept and implement the site change control and return to business as usual.

e.g. Consider a mAb for rapid scale-up. Pharma company A identifies a suite. It has a DeltaV control system and a matching equipment train.

SOLUTION

In this example, the central design team would deploy a virtual DeltaV suite of servers qualified to run the product. SOP's would be delivered from the central design team as well. Practically, everything needed from an automation and batch management perspective is centrally deployed, so that the local site merely has to follow the new centrally established SOPs.

Once an equipment train is identified, the goal should be to decouple the existing DeltaV control system servers and import the centrally developed system using Emerson field service or similar.

Field devices will have to be commissioned. The most efficient way will be to reference the specific existing DeltaV system. Beyond the process equipment train, the local team would import existing code from the old system for support equipment, such as utilities.

Once everything is communicating on the new system, the operations team should be able to begin using the new, centrally deployed procedures.

FOUR SCENARIOS

SCENARIO 1: CENTRAL MANAGEMENT OF A GLOBAL MANUFACTURING RESPONSE

THE McDONALD'S METHOD

NOTE

This first scenario sounds complex. And it is. But it would be drastically quicker than a traditional 'tech transfer' to the site and ask the site to follow its standard procedures.

Waterfall approach versus a lean inspired approach (McDonald's) summary:

- Underpinning inefficiency in the typical approach is the waterfall model. This model is widely at the core of the industry's current approach to projects.
- The current pandemic response approach has far-reaching, immediate consequences. We must see to a resolution as quickly as is humanly possible to save lives and economies around the globe.
- A small team should work collaboratively and simultaneously on a single unit of equipment at a time.
- Carefully coordinated, parallel teams should be used on each piece of equipment, to expedite the design and implementation.
- This work should be organized around a digital twin of an ideal facility.
- Expert local teams should be in place from week 1 to prepare each facility locally.
- This scenario could deliver unprecedented levels of quality in design and speed of deployment, at an unparalleled scale. The top-down and bottom-up combination would represent a plan of attack built for speed of implementation.

To illustrate this scenario, think of the McDonald's analogy in terms of how they have a centralized standard procedure and methodology that's met with localized expertise to deliver a very consistent experience for customers globally. The pharmaceutical industry doesn't work like this right now, but it needs to consider this model for a COVID-19 rapid response strongly.

CENTRAL DESIGN

- The central design team of process engineers and automation engineers work together.
- Working at the same time on the same requirements with a lean methodology.
- Central construction coordination provides planning and best practice for the local teams.

LOCAL FACILITY PREPARATION

- Starting at the same time as the central team starts, the local teams categorize and identify suitable facilities globally.
- The local process and architecture teams begin the retrofit work.
- The automation team begins the temporary removal of the existing control system.
- The local construction team would begin retrofit activities, especially if a facilities existing equipment train and control system are deemed close enough to what's needed.

FOUR SCENARIOS

SCENARIO 2: EFFICIENT USE OF EXISTING FACILITIES WITH DISPARATE EQUIPMENT

THE AMAZON APPROACH

If the required equipment train is not readily available, it may be best to consider a split in the process, ideally between upstream and downstream. This way, partially correct equipment trains could be rapidly adapted in place, and the product could be transported to the next stage. It may also be worth considering to bring the equipment to the product.

STEP 1

Looking to scale an approach, we should consider evaluating the giant pharmaceutical hubs around the globe with multiple facilities only a few miles away from each other. Even though their processes might differ from one another, a lot of the equipment overlaps. Based on this concept, we can start analyzing the equipment trains and create the division between the upstream and downstream for each facility, and determine how they fit the needed process. We can repurpose these facilities into smaller parts to provide a more efficient and faster solution.

How fast the downstream can run will determine the demand for an upstream process. The supply to the downstream process is always dependent on the capabilities and availability of the upstream. Considering the amount of upstream and downstream equipment and the time it takes for each of the stages to complete, we can develop a timeline for the most efficient way to use the material and the best way to optimize the time beginning to end.

STEP 2

Examine whether it's possible to adapt the process so that it's flexible enough to manufacture components of the process in different facilities before the final combination.

For most of these processes, there are dependencies on materials or previous stages that create a constant delay. Other facilities likely have the capabilities to run the process in part and can do so with modifications to existing control systems and SOPs.

Existing control systems are already validated, meaning that only their alterations need to be documented and tested, saving time and efforts.

Most of the control module layer, as well as the equipment module layer, will require minimum to no changes at all.

A copy of the current phases and recipes and can be used instead of modifying the existing ones, avoiding any rework to put them back to their original state once the facility returns to their previous process. Those copies can be altered and adjusted to fit the new process.

Previously unaccounted for steps, such as transfers between tanks or drains, can be done manually if the efforts of modifying the code are more time consuming than the manual process. Flexible hoses and manual pumps can be an invaluable asset to complete those tasks.

STEP 3

Dedicated, temporary, and safe containment and transport become critical. If possible, we should coordinate in less time-sensitive stages to allow for safe transport.

Product holding tanks would be used and adapted to facilitate the transport of product mid-process.

As soon as we identify the critical parts of the process, we need to work on solving the logistics and materials handling issues to keep the production up and running.

FOUR SCENARIOS

SCENARIO 2: EFFICIENT USE OF EXISTING FACILITIES WITH DISPARATE EQUIPMENT

THE AMAZON APPROACH

- Utilizes the concepts of upstream and downstream to divide process manufacturing stages.
- Looks at the upstream and downstream equipment trains of facilities that don't have the equipment trains required for fully processing a product for re-utilization and adaptation to the new process.
- Allows for process division, meaning that a product can be transported to another facility to continue with the process, instead of modifying the first facility to accommodate all the stages.
- Realizes that pharmaceutical hubs around the world provide the availability of multiple equipment only a few miles away from each other.
- Re-utilizes existing control systems reducing the validation efforts, focusing only on implementing the required changes for the upstream or downstream process.
- Signals that manual steps can be implemented on SOPs to avoid code modifications.
- Temporary product holding tanks can be used to facilitate transport of product to other facilities.

FOUR SCENARIOS

SCENARIO 3: NEW FACILITY WITH DELTA-V CONTROLLED OEM SYSTEMS

THE LEGO BRICK APPROACH

If existing manufacturing capacity is insufficient or inadequate, a new facility can quickly be commissioned using a DCS (Distributed Control System) like DeltaV-controlled OEM systems for the necessary process steps.

The goal of this approach would be to replace the local functionality of the OEM equipment with a uniform DeltaV approach to allow for easy coordination and management between units. It would also allow for reliable and smooth coordination of recipes and overall process unit control and management. Within DeltaV, each unit should have a uniform structure and handshaking rules between them. From a Lego brick point of view, a consistent approach gives the ability to build ahead of knowing what the problem to solve will be. A rapidly configurable equipment train is achievable. Currently, we can quickly configure OEM equipment physically, but the software control isn't typically up to a high uniform standard. OEM equipment lends itself to rapid reconfiguration within an equipment train. However, it's not easily maneuvered from a control standpoint. Combining the physical flexibility of the OEM equipment with the traditional DCS robust control approach would result in a powerful combination.

STEP 1

Develop a DeltaV library ahead of time to cover all possible unit operations needed for production. The code for each unit will be validated, allowing for the quick deployment of equipment trains.

DeltaV provides a standardized, flexible platform that can be centrally managed and modified and is often more robust than the vendor-supplied automation. Once a database is created and validated, distribution across multiple systems and sites will be easy.

STEP 2

Engineering identifies which process steps are needed for production. DeltaV code is developed to interface with each of the individual OEM systems. Communication protocols and modules will be created ahead of time, but there won't be restrictions on which OEM vendor provides which system. For example, Vendor A provides a bioreactor, while Vendor B provides TFF and chromatography systems.

Furthermore, multiple vendors can provide the same unit operation, which will avoid relying on a single vendor for all systems. Since DeltaV will control all unit operations, each process step will have the same look and feel regardless of the OEM system in use.

STEP 3

The DeltaV code and equipment remain commissioned and in-place for future production. Alternatively, the equipment and DeltaV library can be repurposed to support the manufacturing of different products altogether.

DeltaV provides a robust method of control that can be quickly modified using validated library objects, to support various manufacturing goals.

THE LEGO APPROACH:

- Is driven by the need for simple plug and play capability.
- The current reality for how OEM equipment is used on-site is subpar because the automation solutions provided by OEMs are typically not a part of their core business and are often poorly supported.
- A DCS (Distributed Control System) approach that provides plug and play functionality Would allow for a real leap forward in speed of implementation.
- Is the best scenario in terms of what can be done ahead of a clear path forward.

FOUR SCENARIOS

SCENARIO 4: ADAPTING CONTINUOUS MANUFACTURING

THE APPLE APPROACH

If it's impossible to take a batch process and replicate the entire process, it would be wise to have a continuous manufacturing effort developing simultaneously. The early stages of this approach are difficult. Without a doubt, this scenario would require a blend of individual and collective effort to create something new and mind blowing. The odds aren't stacked in favor of this. However, significant advances have been made in what would be required to adopt a batch process into a continuous process.

More than any other scenario, this one would sink or swim based on whether the right people are involved. It's akin to the efforts of Apple building the first Mac computer, which not only changed the personal computer but ushered in a new age of creative freedom and advancement of ideas with computers. Steve Jobs described the personal computer as a bicycle for the mind. Apple brought us a new graphical user interface and a computer that was a decade ahead of its time. Continuous manufacturing would have a similar reality-altering effect in terms of production capability if it could be understood well enough to be utilized widely.

Continuous production is especially tricky when it hasn't been considered during process development. However, it's not impossible and would have a significant upside in terms of capacity. Continuous production could mean effectively doubling or tripling the output of each piece of equipment because of the elimination of the dead time between batches.

It may be possible to have a continuous process with no predefined run time or batch size. This would allow for increased flexibility, especially around changing market demands.

STEP 1

Mobilize a central design team to implement process development, design, and implementation. A central team of process engineers must lay out the steps needed to make the product. The automation engineers need to write the control system code simultaneously. The critical task is adopting an assumed batch process with a robust safety strategy.

STEP 2

Continuous means adoption of PAT (process analytical technology) for inline testing. This is best done in concert with a manufacturing execution system. A stable continuous manufacturing process will most likely be of a larger order and more technologically integrated compared to a traditional batch process.

Unlike a batch process, a continuous process can be designed in a steady state. The critical process development part is understanding the amount of time it takes the process to move through each unit of operation. This time is crucial to understanding the controllability of the entire process.

STEP 3

Developing the control strategy will focus heavily on the unit to unit communication and management within the DCS (Distributed Control System) and the coordination of equipment via the MES (Manufacturing Execution System). There is no need for a batch recipe layer beyond the coordination of equipment into its steady-state.

FOUR SCENARIOS

SCENARIO 4: ADAPTING CONTINUOUS MANUFACTURING

THE APPLE APPROACH

STEP 4

Continuous processes generate significantly more data than their batch counterparts. Use of statistical analysis and machine learning is essential with an AWS machine learning (Amazon Web Services) or Quartic.ai (Life Sciences Focused Machine Learning). Machine learning data sets would be qualified with rules for artificial intelligence driven process changes.

It's important to mention that only artificial intelligence that can be quantified and fully validated could be considered for this type of purpose. Often, it's referred to as glass box AI (meaning the algorithms used to make decisions are visible and can be qualified), and not black-box AI (meaning no visibility into the algorithms and how exactly it makes decisions). Any artificial intelligence used to inform changes to how a batch is made, is something that must be thoroughly understood and closely monitored.

THE APPLE APPROACH:

- Is rooted in innovation. The possibility of continuous manufacturing provides an opportunity for a massive leap forward in product output from an equipment train.
- Is complicated and challenging to get right. This approach presents the most challenging scenario. However, it's also the scenario that offers potentially the highest reward.
- Realizes that Apple used hardware and software engineers who were artists at heart. This scenario requires people with an astounding pharmaceutical manufacturing capability to learn how to adapt new technology into the process.

CONCLUSION

OPEN CALL FOR COLLABORATION

The global COVID-19 outbreak presents a unique opportunity to do something groundbreaking as an industry, and adopt a collaborative mindset, rethinking the way we work and solve problems.

We can overcome this massive task before us. All it takes is a calm assessment of all the assets and resources we have on the planet and then set our best people to work on the problem. The rest of us will need to pull together and clear the before mentioned roadblocks.

Brainpower, know-how, and a willingness to think outside the box stand between millions of people dying and months of delays. Now is our time to step up as an industry. The patients are waiting.

Let's put our heads together and start the conversation. We're excited to hear from you.

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