Bringing Lean Strategies to the Process and Hybrid Industries

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Introduction to Lean Manufacturing

Lean manufacturing is one of most important business processes in manufacturing today. Started in the mid-1940s by Toyota as the Japanese company was trying to catch up with U.S. carmakers, it was developed and implemented by visionaries at the company over a period of about 30 years. Called the Toyota Production System (TPS), it relies on two important concepts: *just-in-time* (JIT) and *automation* (or "automation with a human touch"). The goal of TPS is to eliminate any form of waste from the production system.

In the mid-80s and early 90s, many automakers followed Toyota's example and tried to replicate the benefits of TPS. More recently, companies in many other manufacturing industries, including electronics, office furniture and telecommunication equipment, have successfully gone "lean." Not surprisingly, most successful lean implementations are found in the discrete industries characterized by high volume, repetitive operations and assembly lines. Due to these characteristics, lean is an excellent fit for overcoming many of the challenges faced by these companies.

Unfortunately, there are fewer applications of lean manufacturing in the process and hybrid industries, in part because there is no natural fit for lean in these industries and manufacturing processes in these industries tend to be very complex. Indeed, it is difficult to adapt lean manufacturing strategies that have been implemented in discrete manufacturing to the process and hybrid industries.

Therefore, our objective with this paper is to propose an effective way to implement lean manufacturing in the process and hybrid industries. After a brief review of lean objectives and techniques, we discuss *lean principles* and illustrate how they can be applied in the process and hybrid industries. This is followed by a systematic analysis of challenges in the process and hybrid industries, a brief introduction to IBM® ILOG Plant PowerOps (PPO) and a case study that describes how PPO helps manufacturers implement lean strategies in the process and hybrid industries, together with a detailed evaluation of the implementation's benefits.

Lean objectives and techniques

The main objective of lean manufacturing is to provide the best possible service to the customers through the elimination of all forms of waste. Waste can take the form of material or energy waste, inventory, defects or wasted capacity. Manufacturing execution must be tightly synchronized with supply chain plans and customer orders so that the ideal throughput of the manufacturing process is equal to customer demand (Takt time).

The elimination of waste requires a continuous improvement process in which workers are capable of quickly detecting and effectively solving problems. It also requires a highly stable production system achieved through production smoothing, that is, a manufacturing process focusing on a constant volume and product mix.

Figure 1: The Toyota Production System: principles, techniques and objectives, adapted from [5]

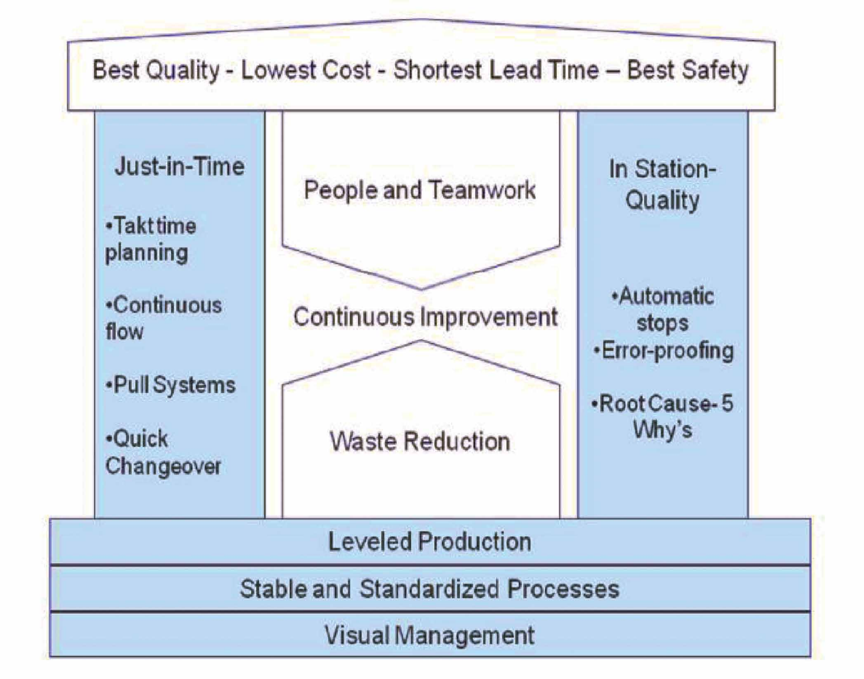


Figure 1, adapted from "The Toyota Way" [3], represents TPS's principles, techniques and objectives. Specifically, Toyota identified several techniques that helped the company create one of the best run manufacturing processes in the world and achieve the highest quality and service at the lowest cost.

For example, Kanban cards are used to control work orders, implement pull scheduling (see [1] and [4]) and reduce work-in-process (WIP) inventory. A Kanban card is associated with each item in production and is used to trigger new production in the system. The number of cards controls the amount of WIP in a specific area [1].

A strong emphasis is put on production smoothing through constant volume and constant product mix, where, in the ideal situation, products should be produced in fixed quantities and fixed production wheels [2]. This is achieved using *Takt time*. Takt time is the frequency of consumer demand and its goal is to make sure this frequency is close to the frequency in which parts are produced in the system. If the frequency of production is greater than the frequency of demand, we start building inventory (i.e., waste). If the frequency of production is smaller than the frequency of demand, we have wait time, shortages and low service levels. Through monitoring Takt times, Toyota was able to smooth production and to define optimal capacity utilization. In order to implement constant volume and constant product mix, considerable attention is given to implementing quick changeovers and reducing lot sizes, in order to be able to make every piece every day.

In this context, teamwork and empowering employees become essential. In fact, the low levels of WIP inventories, or buffers, uncover problems as soon as they arise. Problems are detected very quickly and disrupt the production system. Workers must have the ability to stop the production line and as a consequence, fix the problems as soon as possible to restart production. This not only leads to detecting problems very quickly, but also fosters problem-solving capabilities.

The ability to stop the production line and solve problems quickly is essential to lean manufacturing. In this manufacturing strategy, flexibility becomes extremely important and is achieved through worker cross-training.

Lean principles

Lean techniques have been clearly driven by the requirements of assembly line manufacturing and tuned for the Toyota manufacturing environment. Achieving similar results in different manufacturing environments requires an understanding of the key lean principles.

Researchers have identified four key principles to lean manufacturing (see [1]):

- **Take a holistic view:** The production environment is a system that needs to be optimized as a whole. The objective is to closely coordinate operations that are physically separated.
- **Attention to details:** Operational details are strategically important in lean manufacturing. The focus on setup reduction is a good example. Instead of ignoring setups or taking them as a fixed constraint of the system, engineers try to reduce the setup time so that nonproductive operations are minimized.
- **Control WIP;** Controlling WIP is an important objective achieved through the use of Kanban cards. The key idea is to change the manufacturing process from a “push-based” manufacturing process to a “pull-based” manufacturing process. Demand triggers production activities and gives the right production frequency.
- **Reduce cycle time:** Reducing cycle time is a key objective in lean manufacturing. It is achieved by reducing setups and delays, coordinating machine maintenance with production operations and optimizing space in order to better utilize workers, equipment and workstations.

Implementing Lean in Process and Hybrid Industries: Key Challenges

The process and hybrid industries face many important challenges. These include:

- **High demand variability** — often generated by promotional activities, new product introductions, product phase-outs and interactions with large retailers.
- **High pressure and strict constraints on product quality** — generated by various regulations (For example, sanitary regulations), in addition to shelf-life constraints.
- **Strong focus on cost reduction and return on asset**—manufacturing and supply chain costs are often the most important competitive dimension for companies producing commodity products.
- **Higher frequency of schedule changes**—schedule changes used to be necessary once a week, while today the expectation is that planners will change schedules on a daily basis. The higher frequency of schedule changes generates an increase in setups and manufacturing costs and introduces production variability.
- **High pressure to increase service level** — while reducing inventories.

These challenges are quite different from those faced by the automotive industry, or more generally by discrete manufacturing companies. And they are driven by the different characteristics of each industry, as is illustrated in Table 1 below.

Table 1: Characteristics of the process and hybrid industries that make "lean techniques" hard to apply.

Toyota (repetitive manufacturing)	Process and Hybrid
Low product mix	High product mix
Dedicated resources	Resources shared throughout multiple products and families
Low demand variability	High demand variability
Lot sizes can be reduced (single piece flow)	Physical batching constraints (for example, tanks)
Short setups or setups can be reduced	Long physical setups that cannot be reduced (for example, cleaning in place)
High volume	Mix of high and low volumes
Stable and reliable process	Variability in the process (for example, fermentation, reactions and cell growth)
Low resource utilization	High resource utilization
Infrequent product changes	New product introductions and phase-outs
Infrequent schedule changes	Frequent schedule changes

It is easy to see that implementing Toyota's lean techniques can be not only very challenging in the hybrid industry, but worse: it can generate very poor manufacturing performance if not implemented correctly. For example, reducing lot sizes in the process industry may lead to waste through low utilization of tank capacity.

More generally, it is not clear how to implement a pull strategy in a production process characterized by strong economies of scale and/or requires batching. If raw materials and intermediate products are produced and stored in tanks, it becomes very difficult to implement pull scheduling and a one-piece flow process (that is, a process in which each product moves through the process one unit at a time) as is done in the Toyota model [1]. Similarly, the Kanban concept is appropriate for discrete manufacturing, but impossible to implement in the process industry.

Quick changeovers can be very ineffective, difficult or even impossible to achieve in the process industry. For example, in the food industry a flavor change may generate a purge, which generates wasted product. In the pharmaceutical industry, a cleaning in place may require a full day and in the chemical industry, a changeover may require reconfiguration of a plant.

Achieving smooth production may also be very difficult when some products require high volumes and others low volumes, or when demand is volatile. Machines cannot be dedicated to a single product family and the bottlenecks continuously move from one area of the plant to another. Computing capacity utilization and inventories with simple rules of thumb based on Takt times or “zero inventories” are no longer appropriate.

Therefore, classic lean techniques cannot be applied in the process and hybrid industries. However, lean principles can be applied to identify requirements for implementing effective manufacturing strategies in the process and hybrid industries:

- **Take a holistic view** —sequencing and scheduling decisions must be made by looking at their impact on both resource efficiency and inventory levels and including information about raw materials, intermediates and finished goods.
- **Attention to details**—operational details must be taken into account when generating production plans and schedules. Building a plan that ignores key manufacturing constraints such as tank capacities, cleaning rules or sequence-dependent changeover times will generate continuous adjustments to the plan. Infeasible plans generate many unplanned changes, which create more changeovers and waste. Additional changeovers generate loss of capacity and inventory shortages, which in turn generate expedite orders and new infeasible plans.
- **Control WIP**—controlling and reducing WIP can be achieved by carefully coordinating intermediate product production, finished good production and demand signal.
- **Reduce cycle time**—cycle time includes two components: wait time and processing time. Wait time is reduced by better coordinating the flow of material (for example, intermediate products and finished goods), while processing time reduction is achieved through carefully optimizing the balance between changeover times and costs and inventory costs.

These requirements show that both the old material requirements planning (MRP) logic and some simple rules that work well in discrete manufacturing become inadequate when trying to achieve operational excellence in the process and hybrid industries. They also suggest that there is a need for effective optimization methods that take a holistic view of the production process and balance the various trade-offs while considering all business constraints and provide planners with enough flexibility to easily and effectively modify production plans.

IBM ILOG Plant PowerOps

PPO is an integrated planning and scheduling application that meets the complex challenges of the process and hybrid industries. Bridging the gap between manufacturing execution systems (MESs) and enterprise resource planning (ERP) systems, PPO is a key element in improving companies' flexibility and real-time responsiveness.

PPO's strengths are based on the combination of three elements:

- Precise modeling of the key manufacturing constraints of the plant floor
- Decision support for planners
- Sophisticated optimization models and engines that enable planners to globally optimize production from demand to raw materials and find complex trade-offs among conflicting goals

PPO is able to take into account plant-floor constraints such as tanks, cleaning policies, sequence dependent changeovers, convergent and divergent material flows, intermediate products and shelf life. Detailed models enable the system to generate schedules and mid- and long-term plans that are both feasible and optimal. PPO's plans can be executed with minimal user intervention, helping planners to focus on managing exceptions instead of spending time manually repairing schedule breakdowns.

With PPO, production planners and plant schedulers are empowered with a true decision-support system that enables them to modify the generated plan and validate the manually modified solution with sophisticated alerts and explanations. Using the scenario management interface, supply chain executives and operations managers can simulate alternatives, compare them throughout key manufacturing metrics and make the recommendations that efficiently meet business objectives.

Today, IBM ILOG is the unchallenged leader in optimization technology. The product of ILOG's more than 20 years of experience in solving the most challenging planning and scheduling problems, PPO is the only system that provides an integrated model for planning and scheduling, helping planners to better align manufacturing with demand. They can find the best trade-offs among supply chain and manufacturing goals, such as stock coverage, service level, operational efficiency, cycle time reduction and minimized changeovers.

Industries characterized by high product mix, shared equipment, physical batching constraints and numerous regulatory compliance constraints will gain the most from the sophisticated planning and scheduling capabilities of PPO. Efficiency gains include reduction of waste and manufacturing costs, better management of variability and improved synchronization between manufacturing execution and supply chain plans and improved throughput and reduced planning and scheduling cycle time.

Lean Manufacturing: A Case Study

The case study that follows is based on a real PPO implementation in the fast-moving consumer goods industry. The study is based on the comparison of production plans manually generated by experienced planners against production plans generated by the same planners using PPO with the same data.

The manufacturing process is a relatively common process that can be found in the food and beverage, pharmaceutical and chemical industries, as shown in Figures 2 and 3. Intermediate products are built in production tanks and continuous equipment and stored in storage tanks. Finished products are produced in filling and packaging lines.

Chocolate, tobacco, ice cream, pharmaceuticals and detergents are all examples of products that share similar manufacturing complexity:

- High product mix, with new product introductions and phase-outs, very volatile demand and high service level requirements
- Shared resources, both for production and cleaning
- Tight shelf life and maturation time constraints both for intermediate products and finished products
- Multistep recipes in continuous equipment, production tanks and storage tanks
- Cleaning in place and traceability regulation

Figure 2: Schema of a typical ice cream manufacturing process

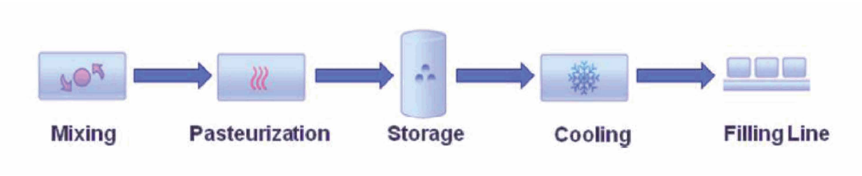
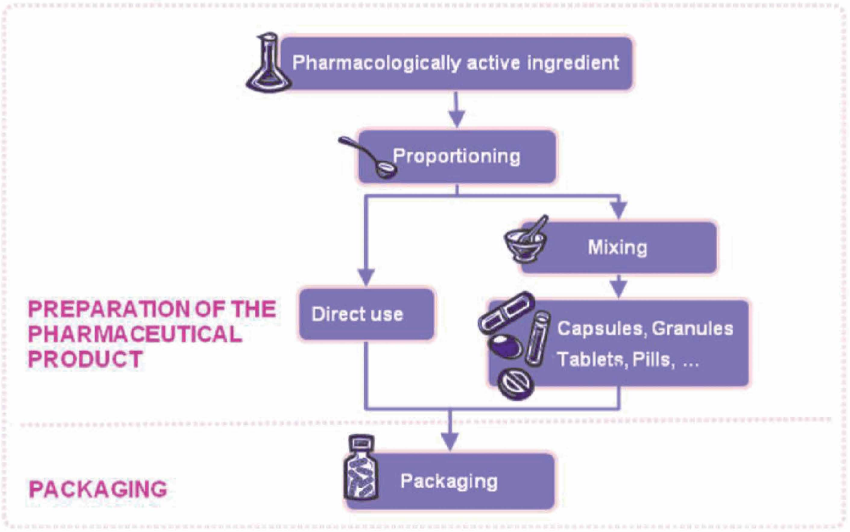


Figure 3: Schema of a typical pharmaceutical manufacturing process



The main objectives of the project were to reduce product waste and cycle time and improve the planner's ability to make optimal decisions faster than before.

Clearly, this customer cannot meet these goals by applying traditional lean techniques created for assembly lines. Kanban cards cannot be used, as setups are very time consuming, generate product waste and cannot be reduced. Finally, batch sizes are tightly connected to the physical capacity of the tanks.

As we explained earlier, the appropriate approach to achieving these goals is to look at the lean principles, rather than the lean techniques. In the hybrid industry, these principles can be translated into a different set of techniques, all empowered by PPO:

1. One integrated planning and scheduling model. Decisions on production quantities, WIP and stock coverage should be tightly linked to sequencing and scheduling decisions. Using a single integrated planning and scheduling model, planners are better able to synchronize manufacturing execution with demand signals and find the right trade-offs between operational efficiency, asset utilization, inventory coverage and service levels.
2. Since Kanban cards cannot be used, the coordination of the material flow and WIP minimization is achieved by planning and scheduling both intermediate products and finished goods in tight coordination.
3. In order to generate a schedule that is executable on the plant floor, the key manufacturing constraints need to be taken into account by the planning and scheduling system.
4. The planning and scheduling system must enable planners to quickly generate new plans, analyze the quality of a given plan and change it by easily overriding the system's decisions.

We implemented PPO and analyzed the results in terms of inventory coverage, production smoothing and operational efficiency.

Inventory and WIP analysis

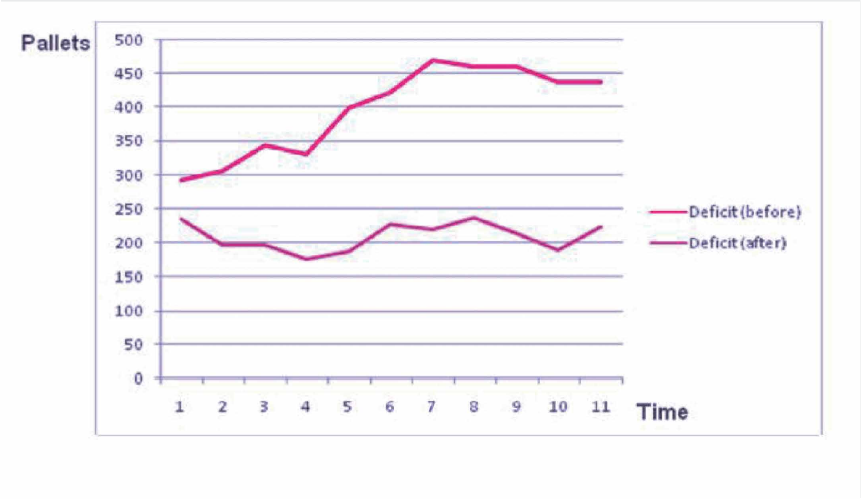
The customer uses inventory targets expressed in minimum and maximum days of supply. An excess inventory occurs every time the inventory position is above the maximal days of supply, while an inventory deficit occurs every time the inventory position is below the minimum days of supply.

Obviously, with infinite capacity and zero changeover costs, the inventory position would always be between the minimum and the maximum days of supply. In reality, the optimal inventory position will tend to move from the minimum level to the maximum level as regularly as the capacity constraints (and changeovers) will help, creating a saw-toothed pattern.

In order to evaluate the impact of the PPO implementation, we measured, for a given set of stock keeping units (SKUs), the inventory excess and deficit and we compared this value against the inventory excess and deficit of a manual plan.

Figure 4: Inventory excess (violations of target stocks)

Figure 5: Inventory deficit (violations of safety stocks)



The results are shown in Figures 4 and 5 and clearly demonstrate a strong reduction of inventory excesses, which went almost down to zero and deficits.

PPO was able to achieve these results by finding the right balance between inventory costs and changeover costs under tight resource capacity constraints.

Note that the decrease in inventory excess not only leads to a reduction in inventory costs, but also leads to a reduction in the risk of product waste, as these products are subject to obsolescence.

The reduction in inventory deficit is also important. Using PPO, planners can now better respect the safety stock targets and these targets can now be recalibrated to manage unexpected events during execution.

Cycle time and operational efficiency

In terms of manufacturing performance, the most important result was a significant improvement in operational efficiency. Roughly speaking, operational efficiency is defined as the ratio between the operational time and the net production time and it provides a good measure of how well the equipment is used.

When a plant runs at very high capacity, any increase in operational efficiency directly translates into an increase in throughput. More important, if a plant runs at very high capacity and the market is growing (that is, demand increases), any increase in operational efficiency generates an increase in sales and a delay in capital investment.

As mentioned before, the reduction of changeover time is a key component for the reduction of cycle time. In fact, cycle time is made of two components: wait time and processing time. The wait time is reduced by better coordinating intermediate products and finished goods, while the processing time is shortened by reducing the changeover times.

The results obtained are reported in Table 2 below and illustrate a significant improvement over the manual process: operational efficiency was improved by values ranging between 2% and 5%, while the total time due to non-productive activities such as cleaning-in-place and changeover was reduced by values between 10% and 40%. Obviously the reduction of changeovers and cleaning and the increase in operational efficiency are linked. In fact, operational efficiency is defined as the ratio between the operational time and the net production time and the reduction of changeovers and cleaning implies a reduction of operational time without impacting the net production time.

Table 2: Improvements over manufacturing KPIs

KPI	Improvement
Operational Efficiency	[+ 2%, +5%]
Changeover time and cost	[-10%, -40%]

Production smoothing

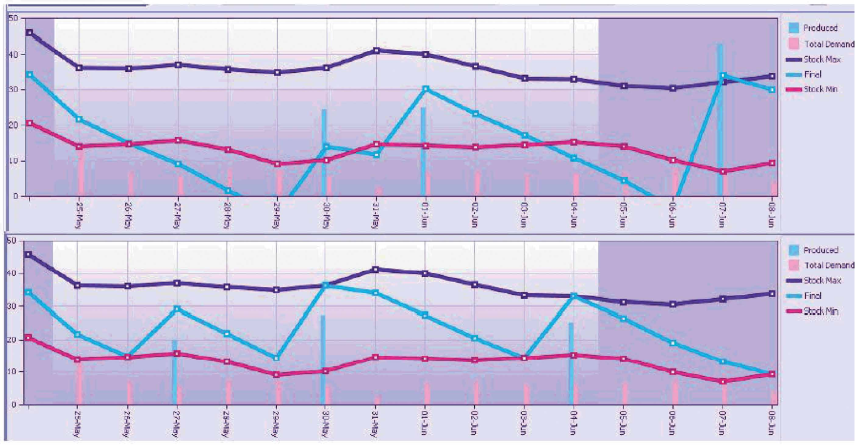
The ability to achieve smooth production even when faced with high demand variability is critical in creating a lean production system. In the hybrid industry, production smoothing should be measured in terms of both production frequency and production volumes.

In the ideal situation, high-volume products should be produced in fixed quantities and fixed production wheels [2]. Unfortunately, this is not always possible:

- High demand variability and physical batching constraints of intermediate products make fixed production quantities infeasible
- High changeover costs push low- and medium-volume products to be interleaved with high-volume products

Figure 6 depicts the production frequency of a manual plan against the production frequency of an optimized plan. The red and blue lines represent the minimum and maximum inventory targets and the green line represents the inventory position. The blue bars represent production and the pink bars represent demand.

Figure 6: Comparison between the stock coverage of a manual plan and the stock coverage of an optimized plan



It is easy to see that the production frequency of the optimized plan is significantly more stable than the frequency of the manual plan.

Figure 7 depicts the production variability (in volume) of different SKUs. Production variability is defined as the ratio between the standard deviation and the mean of production quantities. Again, it is easy to see that the optimal plan has lower variability, leading to better utilization of resources.

Figure 7: Reduction in production variability

Conclusions

By overcoming MRP problems, lean methodologies have helped discrete and repetitive manufacturing industries better synchronize demand signal and execution to produce high-quality products at lower costs.

While traditional lean techniques are inadequate for the process and hybrid industry, lean principles can be applied here but require a different set of tools. While the first-generation APS systems still mimic MRP logic and do not take into account plant-floor constraints, manufacturers can now benefit from a new generation of planning and scheduling software that helps planners deal with the complexity of high product mix, shared equipment, physical batching constraints and numerous regulatory compliance constraints.

PPO helps implement lean principles by providing an integrated planning and scheduling model that takes into account the right trade-offs between supply chain goals and manufacturing goals. Taking into account key manufacturing constraints, PPO closes the gap between planning and execution by enabling planners to generate plans and schedules that are truly executable on the plant floor.

Acknowledgment

This paper has been greatly inspired by the work of Lean thought leaders such as James P. Womack, Daniel T. Jones, Daniel Roos, Shingo and Ohno.

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