HOERBIGER 1-1-1 Turning High-Mix / Low-Volume Manufacturing from a Constraint into a Competitive Advantage

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Abstract: Manufacturers are under constant pressure to better serve their customers while being more productive and flexible. Especially small and medium manufacturers, operating in high-mix / low-volume environments, struggle to manage this additional complexity - often caused due to a lack of applicable information and automation technology. The next industrial revolution paves the way for new disruptive technology that is capable to cope with complex high-mix / low-volume requirements. Flexible industrial robots, intelligent workpiece holding, advanced sensor technology, analytical data platforms and other innovative developments, enable high-mix / low-volume manufactures to significantly change current approaches and procedures. HOERBIGER takes advantage of the new opportunities provided and strives to turn their high-mix / low-volume manufacturing business from a former constraint, into a future competitive advantage. Guided by the visionary target “1-1-1”, Lot Size 1 – Throughput Time 1 Day – Number 1 in all disciplines and a long-term phased approach, first pilot projects have been initiated in 2015.

Key words: Lot size 1, high-mix / low-volume, manufacturing, competitive advantage, flexibility, productivity.

1. Introduction

HOERBIGER is active throughout the world as a leading player in the fields of compression technology, drive technology and hydraulics. In 2015, its 6,858 employees achieved sales of 1.115 billion euros. The HOERBIGER brand is synonymous with performance-defining components in compressors, industrial engines and turbines, automobile transmissions, and multifaceted mechanical engineering applications. Innovations in attractive technological market niches are the basis for components, systems and services that offer unique selling propositions and long-term benefits for the customer.

Through unique selling propositions, HOERBIGER provides a lasting contribution to the added value of the Group’s customers. Driven by a high corporate ambition associated with this performance commitment that HOERBIGER derives the vision of the HOERBIGER Group: We set standards.

To achieve this vision, HOERBIGER’s mission is focusing on excellence for products, services, management and operations. Led by the ambitious vision and mission, Strategic Business Unit Compression Technology and its Production Division are currently transforming the global production network to become customer oriented, strategy driven and improvement focused. Excellence in all areas of operations - for all global and local entities.

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initiatives in Production Division to develop a highly flexible and highly productive “next-level” production system by taking advantage of innovative technologies. The first chapter describes challenges operating in a complex high-mix / low-volume environment. Based on these challenges, the second chapter highlights the design and content of a new, recently communicated “Vision 1-1-1”: Lot Size 1 – Throughput Time 1 Day – Number 1 in all Disciplines. Building on that, an exemplary pilot project will be highlighted in chapter three. In conclusion, chapter four summarizes the most important results, outcomes and success factors.

2. High-Mix / Low-Volume – A Constraint or a Competitive Advantage?

The most critical step to further enhance a business is to fully understand the current situation and environment it is operating in. As a starting point, Production Division explored its internal and external complexity, driven by customer and market requirements.

2.1 Complexity – A Necessary Evil

For more than 120 years, the Strategic Business Unit Compression Technology of HORIBIGER has positioned itself as innovative market leader providing performance-defining components, systems and services for reciprocating compressors, gas-fueled engines and turbines in the oil, gas and process industry. The mentioned industries show in general a high degree of external complexity for companies operating within. The complexity is driven by global supply chains, long investment cycles, dependency on raw material price developments (e.g. oil and polymer) as well as highly volatile customer demands. Global trends and developments such as increasing competition, political changes, new technologies, resource bottlenecks or the digitalization further increase the external complexity [1].

Driven by the industries, markets and customers, Production Division faces additional, business specific, internal complexity factors. Customized products, individualized for the specific customer application, result in a high variety of about 1,300,000 parts and components in the system. The expected lead times in order to deliver the products are decreasing continuously, leading to volatile customer order patterns of about +/- 30% week over week. Production lot sizes of 10 and lower increase the number of machine setups, reduce overall equipment efficiencies, limit feasibility of process automation and, by doing so, drive manufacturing costs up significantly. All the mentioned above needs to be managed in a global setup, running more than 10 production plants in Europe, USA and Asia and serving several thousand customers.

In such an environment, the general advantage of building up inventory to reduce the complexity in production is very limited. Increasing inventory levels while at the same time not knowing if and when the variety of products are going to be sold, is considered to be economically intolerable. Hence, production is challenged to provide a production system, capable of managing the complexity driven by high product variety, short lead times and low lot sizes, in a flexible and productive way.

2.2 High-Mix / Low-Volume Production Systems

Traditionally, production systems specifically designed for such environments, can be categorized as high-mix / low-volume production systems. Those production systems, such as job shops, provide the flexibility to quickly adapt to changing requirements in regards to capacity, technology and/or labor skills. However, they are usually limited in terms of productivity. A high variety of products, short lead times and low lot sizes cause many machine setups. While being necessary to adapt the production system to new requirements, the setups reduce the overall equipment efficiency and respective productivity levels. Additionally, a high number of setups for a
variety of products is limiting productivity improvement opportunities provided by automation technology and new equipment introductions (e.g. machine tools).

Due to increasing pressure of global markets, Production Division faces the challenge to further develop their high-mix / low-volume production system to reduce costs and to disproportionately increase productivity at the same or higher level of flexibility. To address this challenge, Production Division defined two generic goals, highlighting the direction for the future development of its high-mix / low-volume production system.

2.2.1 Increase Productivity Significantly - without Losing Strategic Flexibility in Manufacturing

Traditionally, high-mix / low-volume manufacturers have been able to optimize their productivity mostly by organizational changes, visualization and process simplification using LEAN, 5S and other optimization principles. In the future, innovative technology will enable them to implement advanced automation equipment that is flexible and intelligent enough to cope with the demands and requirements of a high-mix / low-volume environment (see Fig. 1).

2.2.2 Manufacture Lot Size 1 at the Cost of Mass-Production

The increasing focus on mass-customized products, shorter lead times as well as working capital improvements, lead to a steady reduction of production lot sizes. Small production lot sizes cause a high number of setups, decrease the equipment efficiency and limit opportunities for multi-machining for the operators. As a result, costs per part are increasing and will, if not being successfully passed on to the customer, impact your financial margins negatively. By minimizing the required number of setups towards “zero setup”, high-mix / low-volume manufacturers will be able to manage their cost per part independently of lot sizes and enable extended multi-machining approaches with high equipment efficiencies.

Easier said than done. Experiences from recent years show, high-mix / low-volume manufacturers in general struggle to achieve a significant change when implementing the two above-mentioned goals. However, current research and developments in advanced manufacturing provide new opportunities for high-mix / low-volume manufacturers, to completely re-think their production system in terms of flexibility and productivity. Especially, but not limited to, research and development driven by the term “Industry 4.0” seems to provide promising approaches to overcome the historical paradigm of flexibility versus productivity and to make a significant shift forwards flexibility and productivity.

2.3 Industry 4.0 – A Game Changer for High-Mix / Low-Volume?

Since the German government first coined the phrase in 2011, “Industry 4.0” has transformed into one of the most hyped topics on the global manufacturing agenda. The basic idea of “Industry 4.0” is commonly considered to fully implement and integrate capabilities of information technology in the manufacturing environment. In addition to ERP-, MES- and other conventional software systems to support the manufacturing process, developments in recent years provide manufacturers with new opportunities such as:

- Unique identification of every manufacturing object in the facility allowing manufacturing information being directly attached to the products.
- Advanced sensor technology to gather manufacturing data that was not available before.
- High-performance algorithms that transform huge amount of data in useful information (“Big Data”).
- Real-time connectivity providing the right information in time.
- Decentral communication between the manufacturing objects (“Cyber-Physical Systems”).
Fig. 1  Transformation of Production Division from a job shop into a flexible, agile and highly productive manufacturer.

- Autonomous decisions supported by advanced simulation capabilities.
- Full integration of all information systems.
- Standardized interfaces enabling a flexible and modular setup.

Continuous progress in the area of advanced information technology can be highlighted as a very essential part when designing future manufacturing environments. However, to fulfill the special requirements of a high-mix / low-volume production system, research and developments need to further extend their scope beyond information technology and add mechanical engineering aspects into the picture. Innovative technologies such as collaborative and sensitive robotics, 3D-printing, intelligent and flexible work-holding concepts need to be further industrialized to fully gain the potential slumbering in high-mix / low-volume production systems.

The above-listed technologies are, to the most part, in an early maturity level of its development. However, some visionary ideas and technologies of the idea “Industry 4.0” in combination with the current hype, might have a leverage to push manufacturers towards the next level of their high-mix / low-volume production systems. Production Division has realized this chance and announced a renewed vision for its manufacturing business.

3. Production Division: Vision 1-1-1

Building on chapter 2, the following chapter describes a new vision for Production Division as well as a derived long range plan for the next 10-15 years.

3.1 A New Vision for the Operations Team

To achieve these ambitious goals towards next level high-mix / low-volume production systems, it is necessary to visualize the most important directions and messages within the organization. Fully in-line with the generic goals to significantly increase productivity in our high-mix / low-volume production system and to manufacture at a cost that is independent from lot sizes, Production Division’s management communicated the “Vision 1-1-1” for all its employees in 2016. “Vision 1-1-1” represents three
major goals for the next years: Lot Size 1 – Throughput Time 1 Day – and Number 1 in all disciplines of operations (see Fig. 2).

Lot Size 1 highlights the need to improve flexibility and productivity together. Customization of product increases and lead to a continuous reduction of lot sizes. Previously not existing economies of scale could be generated by implementing flexible and automated technology. Throughput Time 1 Day is focusing on speeding up the manufacturing process. The faster you produce, the more flexibility you create to cope with your volatile markets. To achieve the first two goals, we need to be the Number 1 in all disciplines of operations – technology, process, talent and all other areas of operations.

The vision drives a significant change in the approach on how to plan, execute, measure and control the manufacturing process in the future. To structure this change process, three integrated phases have been defined in cooperation with Vienna University of Technology. The three phases “Connectivity”, “Virtualization” and “Self-Organization” encapsulate specific technologies, initiatives and projects.

3.2 Phase 1: Connectivity 2020

The starting point for all future activities towards “Vision 1-1-1“, is connectivity in the manufacturing area. The aim of this phase is first to equip every manufacturing object such as materials, parts, machines and tools with modern sensor technology and second, to automatically analyze the gathered shop-floor data through modern data algorithms.

Using sensor technology in the operations environment is not new. Especially logistic applications rely since decades on technologies such as RFID. Additional opportunities provided by information technology (e.g. IPv6) now enable manufacturers to put a unique identifier on each object that is contributing in the manufacturing process. A gapless identification of tools, jaws, chucks, machines, operating supplies, transport and quality equipment provides the opportunity to keep track of all events on the shop floor. Additionally, it is the basis to link the gathered mass data directly with the object itself. Some machine tool suppliers already today equip their machines with different sensors, measuring and saving data about the current machine condition (e.g. water and oil quality, temperature, flow, pressure, vibrations), process (e.g. cycle times, speeds, feeds) and energy consumption (e.g. radiation, electrical power). The amount of data is overwhelming and requires modern data algorithms that extract the important data, link data spots and create relevant information for decision makers in the manufacturing process.

In the first stage, management will use the gathered data to generate continuous improvement savings taking advantage of faster cycle times, improved energy patterns and predictive maintenance. In the

1 Several show-case factories have already been successful in implementing full connectivity in their manufacturing area. See e.g. Maschinenfabrik Reinhausen, Siemenswerk Amberg, Festo Scharnhausen and more.
long run, real-time connectivity sets the stage for the second important phase towards “Vision 1-1-1” in Production Division.

3.3 Phase 2: Virtualization 2025

Building on real-time connectivity, phase two targets the full virtualization of all manufacturing objects and the data flows available. Every real-life object will be provided with a “digital twin” – an exact mirror of the manufacturing object. All real-life events from the shop floor will be captured in real-time and directly reflected within the digital twin. Both, the real object and its digital twin build a continuous information flow between each other (see Fig. 3).

While some specific process steps and objects of manufacturing process have been virtualized already (e.g. part data virtualized in Computer Aided Design tools etc.) many others are still left out of picture so far. Machines, tools and every other equipment required to execute the manufacturing process, needs a virtual representation in order to complete the idea of the “digital twin” for the entire environment. Having a full virtual picture of a high-mix / low-volume manufacturing environment in place, paves the path to a powerful advantage: Real-time simulation of a high-mix / low-volume production system.

The simulation of different scenarios taking into consideration real-time information in a complex environment such as a high-mix / low-volume production system provides manufacturers with significant advantages. Within minutes, management could answer questions in regards to conflicting targets, moving bottlenecks, changing product mixes, optimal layouts and more. By that it has the capability to forecast the impact of changes driven internally and externally, prepare action items and management decisions in advance and therefore increase flexibility and productivity significantly.

3.4 Phase 3: Self-Organization 2030

Phase three is closing the loop back to the real environment by using all above-mentioned to drive automated decisions and re-configurations in the real factory. In order to achieve this final stage of the “Vision 1-1-1”, several elements in regards to autonomy, decentralization, modularization and automation have to be put in place.

To cope with the complexity of a high-mix / low-volume production system, it is in general recommended to design an autonomous and decentralized decision making process.[3] As a result, the more the systems knows about its single manufacturing objects, the manufacturing process and the real-time conditions, the faster it is able to react on required changes on the shop-floor. For example, a machine tool will be capable of adjusting the required CNC program in the manufacturing process by itself.

![Information Mirroring Model](image)

![Real-life Machine](image)

**Fig. 3** The “digital” twin of a machine tool [2].
knowing if certain conditions, such as tool wear-offs or part characteristics, in the system have changed. Thus, a production system consisting of manufacturing objects such as parts, machines and robots, being capable of communicating directly with each other is expected to achieve the most optimized result (see Fig. 4).

While the decentral communication between manufacturing objects provides many advantages to cope with day-to-day shop-floor issues, certain higher-level aspects of a manufacturing environment might still need to be controlled centrally. Using the advanced simulation capabilities described in phase two of the “Vision 1-1-1”, the production system drives decisions about if, when and how to re-configure itself according to upcoming changes such as a different product mix, machine breakdowns or increased short-term customer demand.

Those decisions need then to be reflected on the physical shop floor, making a flexible modularization of the manufacturing equipment a necessity. Using standardized interfaces and flexible equipment such as automated guided vehicles (AGV), advanced, and sensitive robots, high-mix / low-volume manufacturers become capable of changing their layouts, production cells and internal logistic more frequently in order to cope with changing requirements. “Plug & Produce” describes manufacturing systems where cells, robots and other equipment can be addressed via standardized protocols and interfaces (e.g. Service Oriented Architecture; SOA). The effort for taking a robot from cell A handling product B and moving it to cell C handling product D will be reduced to a minimum. The system knows how to address and approach the manufacturing equipment and re-configures it so it can act effectively and efficiently in the new environment. The “setup of the entire factory” as a daily job will become a standard.

A production system that is flexible enough to react to changing requirements while being highly automated and productive at the same time could be defined as the ultimate, visionary goal for high-mix / low-volume manufacturers. The described “Vision 1-1-1” and the three-phase approach support Production Division on its way to achieve this target. Since 2015, first initiatives in phase one, “Connectivity”, have already been initiated.

4. “Vision 1-1-1” Pilot Projects at HOERBIGER

The following chapter is building on the “Vision 1-1-1” and the three-phase approach and provides

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2 See also chapter 4.1.
details on a pilot project that is currently being implemented in Production Division.

4.1 A Successful Approach – Built on Strong Cooperations

Guided by the „Vision 1-1-1“ and the three-phase approach, Production Division is currently implementing first new technologies in the manufacturing area. Being confronted with new manufacturing concepts and technologies, different challenges have been brought up to the surface. Does the skill-set of the employees fit to the new technologies? How to finance disruptive pilot projects? What technologies are really adding value to our business? We countered those questions by following a risk mitigating approach when implementing new technology.

Every implementation of a new technology, starts with a pilot project in a selected pilot production plant. The experience of the pilot project verifies the potential and value-add of the new technology. Following a successful pilot, several roll-out projects will be initiated to spread the new technology in the global production network. The implementation of the pilot project itself turns out to be a critical step for all further activities. Generally, the scope of a pilot will show strong characteristics of an innovation project. Therefore a successful completion of a pilot project needs an increased focus on a professional project management approach and experienced team members. Additionally, experiences made in recent years show that projects result in better outcomes when supported by external partners. Hence, Production Division built up strong cooperations with suppliers, industrial partners and Universities to get additional know-how, scientific equipment as well as additional opportunities for financial grants.

Building strong, trustful cooperations might take several years. Production Division developed such a close relationship with the Vienna University of Technology and the Institute for Production Engineering and Laser Technology (IFT). IFT research is, beside others, focusing on flexible production systems, cyber-physical systems and machine tool technology. Moreover, IFT sets already first steps with pilot show-cases in their laboratories for all three phases “Connectivity”, “Virtualization” and “Self-Organization”. An exemplary show-case is the “Plug & Produce” manufacturing cell, consisting of a raw material stock, a lathe and a material handling robot (see Fig. 5).

In 2015, another important milestone within the

![Diagram](image.png)

**Fig. 5** “Plug & produce” manufacturing cell at Vienna University of Technology / IFT.
cooperation has been achieved. Financed by the Marshallplan Foundation, Vienna University of Technology got the approval to establish the “Austrian Center for Advanced Manufacturing Systems” (ACAMS). ACAMS is a cross-functional department at the IFT, connecting the core competencies of automation technology, information technology and mechanical engineering. Additionally, Production Division and IFT are supporting each other when applying for financial funding programs such as COMET or Beyond Europe.

Following the described approach, a first pilot project of the phase “Connectivity” has been initiated in cooperation with IFT.

4.2 Pilot Project: Manufacturing Data Analytics

A first pilot in regards to the phase “Connectivity” called Manufacturing Data Analytics was started in 2015. The project is a shared effort of the Institute for Production Engineering and Laser Technology, the research company researchTUe, the information technology company Atos and the HOERBIGER Ventilwerke located in Vienna-Aspern (see Fig. 6). The overall aim is to evaluate the savings potential of analyzing mass data gathered out of different machine tools for the production network. For that purpose ten machine tools at the HOERBIGER Ventilwerke have been equipped with special sensors and standardized MTConnect interfaces, providing about 70 GB monthly data. Afterwards, the data is being analyzed and transformed by a modern storage and analytic platform, operated and hosted by Atos, researchTUe and the IFT.

The success of the pilot will determine if the technology can be further established in the production network. Improved productivity is expected by improved data quality for production planning (e.g. setup improvements, higher quality of planning data) and the machining process itself (optimized speeds and feeds, toolpath improvements). Planned productivity increases are expected to provide Production Division with a return on investment below one year.

The above-mentioned pilot project highlights the benefits of strong cooperations. The pilot project has been started without requiring a long analysis and preparation phase. The entire infrastructure was provided by external partners using the “Industry 4.0” show case factory of Vienna University of Technology and researchTUe. Additionally, the pilot project uses state of the art information technology systems, setting the baseline for future developments and roll-outs.

Fig. 6  Cooperation model between HOERBIGER, Vienna University of Technology and Atos.
5. Summary & Outlook

The Production Division of the Strategic Business Unit Compression Technology at HOERBIGER faces a high level of complexity in its manufacturing business, caused by a high variety of individualized products, short lead times and low lot sizes. Such environments require flexible high-mix / low-volume production systems, capable of adapting to various changes. Due to increased customer and market pressure, manufacturers are challenged to significantly increase productivity while keeping the required level of flexibility. Additionally, costs per part have to become independent of lot size by reducing number of setups to a minimum and enable multi-machine operation with high equipment efficiencies. Recent research and developments, especially in the context of digital manufacturing, provide promising opportunities and innovative approaches to solve these challenges in the future.

Based on these promising opportunities, Production Division set up a new vision that is guiding the entire organization to transform manufacturing from a former constraint into a competitive advantage. The “Vision 1-1-1” describes Lot Size 1 – Throughput Time 1 Day – Number 1 in all Disciplines, and is the strategic framework for all future decisions, initiatives and projects. The path towards the vision is split into three major phases “Connectivity”, “Virtualization” and “Self-Organization”. Phase one equips all manufacturing objects with a unique identifier and sensors to achieve full connectivity. Building on that, phase two targets to reflect the factory in a digital twin to simulate the entire production environment based on real-time data and requirements. Phase three is completing the developments and creating decentral and autonomous decision cycles that take considerations from the simulation and re-configure the shop floor accordingly – as automated as possible. Towards that path, a first pilot project in the phase “Connectivity” has already been initiated. The current and all future pilot projects are supported by cooperation partners such as Vienna University of Technology to take advantage of public grants, laboratories and know-how.

When fully implemented, “Vision 1-1-1” will support Production Division to bring its high-mix / low-volume production system onto the next level and to create an additional competitive advantage for the Strategic Business Unit Compression Technology.

The ambitious goals envisioned in the “Vision 1-1-1” will not be realized easily. The authors take the liberty to share ten golden rules that might support other companies and industries on their way to position manufacturing as a competitive advantage in their respective markets:

- Realistic expectations. Putting self-organizing production systems in place is not around the corner. Some of the big benefits might only become effective after the full implementation – not during the way.
- Create your vision. Setting a new vision for your organization is a difficult task. Not everybody is willing to follow you towards that road. Stay focused and step-by-step you will convince not only management but also all other parts of your organization to share the vision with you.
- Search for real value. Evaluate new technology and concepts based on your needs and requirements. Find out what is real value for your company - and what only nice to have. Remember: A lot is possible, but not everything might be necessary.
- Pro-active involvement. Build and manage your scientific network. Relationships don’t build themselves up overnight. Invest in building those relations by visiting shows, conferences and industry partners and learn from their experience and expertise.
- Collaborate. Use Universities and other research entities in addition to your own technical experts and let them support you in the start-up phase with knowledge, hours and equipment. Work with industrial partners and platforms (e.g. Enterprise 4.0) to share the efforts and investments necessary.
• Use public grants. The push for new technology is creating opportunities for financial funding, provided by governments, states, regions and research councils. Use the opportunities given to finance your pilot projects in an early stage.
• Be ahead of the curve. Act as a technology innovator or early adopter. Bringing disruptive technology to a mature level takes time, so the earlier you get started, the better.
• Be persistent. You will face different set-backs on your path. Many variables are not clear before and during the implementation of new technology. Overcoming those issues requires a high degree of structure and consistency.
• Calculated risk. Risk and reward directly correlate. Have the courage to be one of the companies that are now shaping the future of manufacturing. Use a professional project management approach to mitigate risks as much as possible.
• Embrace exciting opportunities. We are blessed to live in an exciting time for manufacturing. Be open-minded, explore opportunities and use upcoming chances. Motivate your team and enjoy the road as much as you can.

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