Ensuring global productivity

The evolution of automated welding in simple programmable welding cells

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1.1 Expanding welding industry

Welding is a trade that requires a high level of material and process knowledge. This fusing method is permanent and faults are fairly difficult to repair or hide. However, metalworking companies are faced with a major shortage of welders, which is due to a combination of different factors: increased production levels, mass customization and an outflow of welders.

1.1.1 Growing demand for metal products

In 2020, the global welding market size was 20.23 billion dollars (Fortune Business Insights, 2021). Up until March 2020, the estimated compound annual growth rate (CAGR) of this market was 6.2% (Grand View Research, 2020), which is in line with the 6% CAGR for the previous decades (Total Materia, 2007). In other words, the market experienced relatively steady growth in recent years. This trend was expected to continue due to residential and non-residential construction in Asian countries, but the coronavirus threw a wrench into the works.

The first corona patients were reported in China at the end of 2019. Few could have predicted that as a result of this the entire world would come to a virtual standstill. The virus spread with such speed that global lockdowns became the norm. Industries that were considered 'non-essential' came to a standstill in many countries.

The overall manufacturing industry, including the welding industry, was adversely affected by this during the initial corona period.

Despite the pessimistic outlook, the welding industry experienced a growth rate of 3.6% between 2020 and 2021 (Fortune Business Insights, 2021) – the expectation is that this growth will continue at an average growth rate of 4.6% to 2028. In fact, this is being stimulated in Europe and America. Little by little, countries were repatriating production – also known as reshoring. Originally, this was primarily due to the considerable increase in wages in low-wage countries, but this development was further reinforced by the impact of the global pandemic on the supply chain.

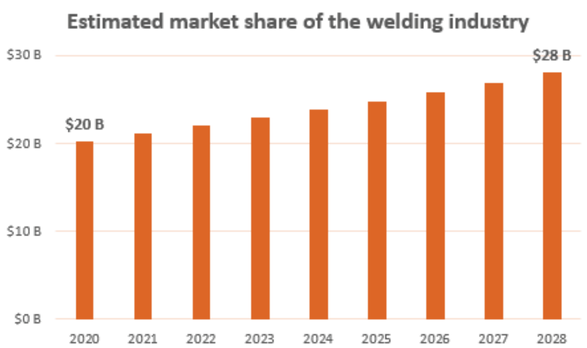

Figure 1:
Projected market share of the global welding industry. Based on Fortune Business Insights (2021) figures.

1.1.2 Mass customization

Since the beginning of the industrial revolution, the production of goods has risen. Due to serial production, the variation in goods was drastically reduced. However, in recent decades the trend has been for consumers to demand personalized products, without having to compromise on the efficiency of mass production: mass customization (Gandhi et al., 2014).

This demand originated in the fashion industry, but quickly spilled over into the automotive industry. Other markets have since followed this industry in recent years, including the welding industry. An example that comes to mind here is black powder-coated table legs that can be ordered in all shapes and sizes from various webshops.

As indicated earlier, a condition for mass customization is that there should be no compromise on the efficiency of mass production. In our example, this means that the table legs can be ordered in different sizes. However, a condition hereby is that dimensional accuracy must be high, while price must not be disproportionately higher. The serial production of table legs kept in stock therefore is not an option. Instead, local welders are called upon to supply high-quality custom work within a predictable timeframe.

However, mass customization is not limited to the consumer market alone, but is also evident in the business-to-business market. As indicated above, reshoring is a phenomenon that arose in recent years to reduce delivery times, as well as transportation costs, in order to once again become competitive in the market as a European or American company. In the machine, residential and non-residential construction sectors this manifests itself, for example, in custom frames that are manufactured from laser cut pipes, tubes or sheet-metal work. One of the fusing methods used for this purpose is welding, which in turn means that even greater demands are being placed on the local welding industry.

1.1.3 Outflow of welders

So there is a growing demand in the welding industry. The market continues to grow, even with a global pandemic. The question as to whether there are sufficient welders to cope with this increased demand is compelling. The Economical Modeling Specialists International (EMSI) and the American Welding Society (AWS) are expecting a rising shortage of welders in the coming years. In 2019 it was estimated that by 2023 there would be a gap of as many as 375,000 welders between market demand and available welders in the working population in North America (Guerra, 2019). Even four years prior to this, AWS estimated that there would be a shortage of 400,000 welders in 2024, which does not deviate all that much from the above-referenced figure (Tasch, 2015). This is just over 60% of the 609,000 North American employees working in the welding industry in 2019 (DataUSA, n.d.). According to AWS this shortage would go up even further due to the large upcoming outflow of welders who are due to retire over the coming years.

In 2022, AWS reanalyzed the data to produce a new estimate of the shortage of welders in the near future (AWS, 2022). Since the 2019 estimates, a great deal of work was done in the United States to train future welders. This is why the shortage of welders in 2026 is lower than was estimated the years before, albeit at 336,000 still overwhelming. This means that over the coming years 84,000 job openings would need to be filled each year to offset this shortage.

Figure 2:
The expected shortage of welders in North America by 2026, with a brief explanation of the cause of this shortage, according to AWS (2022).

In Europe, the figures are not encouraging either. For example, in 2021 many Dutch metalworking companies struggled with a major shortage of welders (Geertsma, 2021). This was evident from the large number of job openings. It is not possible to accurately determine the size of this shortage. This is because companies put their job openings online, but on different platforms, quickly doubling, or even tripling, the number of apparent job openings. Geertsma furthermore observes that there is a large variety in requested welding processes: MIG/MAG, TIG and MMA, for example.

In Belgium, there were 449 job openings in the welding sector in 2018 (Vercammen, 2019). While at first glance this does not appear to be all that many, the shortage is growing every year and is already perceptible in the industry. In 2019 for instance, the welding trade show's main focus was on attracting a new crop of welders to anticipate the ever-increasing shortage at an early stage.

Germany is making a desperate attempt to attract trained migrant workers to offset the shortage of skilled workers. There is a need for as many as 400,000 trained immigrants every year to keep up with demand according to Detlef Scheele in an interview with the Süddeutsche Zeitung [a German newspaper] (Hagelüken, 2021). Despite the fact that the number of migrant workers needed has shrunk due to the corona pandemic, this is in stark contrast with the reduced inflow of immigrants.

1.2 Automation has a reinforcing effect

Although the figures are highly divergent or cannot be interpreted directly, the many news reports are right on the mark: the welding industry is growing, the type of work is increasingly varied and there is a perceptible shortage of welders – and something needs to be done about this. The methods to solve this are also divergent: investing in students for future growth or quickly replenishing the labor market by attracting migrant workers. Another method is automation by making use of standalone or collaborative robots.

1.2.1 Robots in the manufacturing industry

From the time that General Motors in New Jersey deployed its first Unimate robot in 1961 (Automate, n.d.), the number of robots has grown to more than 3,015,000 by 2020 according to the International Federation of Robotics (IFR) (2021a). This number has grown especially fast in the last decade: a tripling of the 1,059,000 units deployed by the industry in 2010. In 2020, 384,000 robots were integrated, of which as many as 66,000 in the welding industry.

1.2.1.1 Large series, little variety

Robots have distinguished themselves in the market by their freedom of movement, precision, speed, strength and continuity. With regular maintenance and adjustments, robots can tackle large-sized series with ease. A robot is a manipulator, generally with five or six separately movable axes. Behind the last axis the robot can attain speeds of multiple meters per second. To safeguard the operator's safety, he/she is protected therefore by means of fencing.

In the welding industry, a table is often placed in an opening in the fencing, so that half of the table sticks out on either side of the fence. This virtually creates a revolving door to pass unfinished product parts from the operator to the robot, and finished products from the robot back to the operator. This allows the robot and operator to work in parallel: the robot welds on one side of the table, while the operator removes the welded product and replaces it with new product parts on the other side of the table.

Robots must be programmed to enable them to perform a movement, control external equipment or respond to sensors. Virtually every robot brand has its own programming language, with distinctive functionalities or features. This makes integrating robots a fairly labor-intensive process, and consequently a very costly investment. The costs for safety fencing, sensors and actuators are on top of this. Robot installations deployed in the industry are therefore often characterized by the large series sizes that they produce successively – and virtually exclusively.

1.2.1.2 Robots increase a company's vitality

Companies that perform processes that lend themselves well to automation have a choice: to automate or not to automate. The investment involved must be weighed up against the benefits, but also pays off over time. Turnover, as well as employment increases.

Koch et al. (2019) demonstrate in a study of Spanish companies that especially large and more productive companies make use of robots, while the often smaller companies within the same sector reject robotization. Production among the first group in the four years after acquisition rose by 20% to 25%, while the second group was lagging. The workforce also grew in tandem with automation: among companies that opted for automation, the number of jobs increased by 10%, while employment among the group that did not make use of robots, employment even declined.

1.2.1.3 The robot-personnel skills paradox

Robotization can have two totally opposite effects on the required personnel skills. Because the required process knowledge is embedded within the robot, the robot cell only needs to be supplied with new materials or products. This reduces the skills required from an operator to just placing parts in a robot cell and removing the products (provided that the presence of parts in the machine – and the accuracy of their placement – is captured or enforced by the surrounding sensors or the shape

of the clamping tools). If the robot is also able to operate when parts are incorrectly placed or not even supplied, this can result in faulty production or can even cause damage to the system.
On the other hand, a robot system is a complex system, that also requires more complex skills. Particularly when the company also uses the system to automate new processes. The required process knowledge must be captured in code, which requires process, as well as programming knowledge. Capturing robot positions in code and creating a logical outcome, for example, is insufficient to be able to weld effectively, because parameters, such as the fusion angle, advancing speed, wire supply – and much more – affect the weld's quality.

1.2.1.4 Robotization in the SME sector continues to lag

Robotization is an expensive business that furthermore requires investment in changes in the workplace and the associated logistics processes. According to Malowski et al. (2021a) this proves to be a major obstacle, particularly for SMEs. Linda Kool, Theme Coordinator for the Digital Society at the Rathenau Institute, in an interview by Malowski et al. also indicated that investment consequently is deferred for a longer period of time or is put aside altogether. As a result, these companies lose some of their vitality on the labor market.

Automation by means of robots therefore is not self-evident for small and medium enterprises (SMEs) due to the major investment required for this purpose. In addition, it is also difficult to attract – and retain – staff. Dutch companies currently are already engaged in a real battle for robot programmers (Van der Laan, 2022). They are difficult to attract and even more difficult to retain, because many companies are diligently looking for robot welders that enable them to automate their series-oriented work.

1.2.2 Cobots

In addition to traditional robots there are collaborative robots, also known as cobots. This type of robot has different properties and areas of application in comparison to traditional robots, but they also come with a paradox.

1.2.2.1 Cobots versus robots

In 2004, the German robot manufacturer KUKA introduced the first collaborative robot or 'cobot' to the market. Their LBR 3 was equipped with built-in sensors that made it possible to read out the forces applied at separate axes.
The cobot internally calculates the force to be applied to the axes, for example due to gravity's effect on the arm itself, as well as the effect of the mass the robot picks up. When a deviation is registered, the robot is able to respond to this by stopping or moving out of the way until only the calculated forces are registered.

This characteristic originally was intended to safeguard operators' safety without the need for protective fencing around the robot. However, this also means that the impact has to be limited to a certain maximum. This also is the reason why a cobot generally is somewhat slower and cannot lift as much weight as a traditional robot. By contrast, the biggest advantage associated with the possibility of monitoring external forces is that it proved to be possible to control a cobot by pressing down on it. The cobot can be 'forced' into position by hand, which tremendously simplifies programming the cobot's positions.

The first generation of cobots was not yet appealing financially because the costs of the more expensive technology did not yet outweigh the benefits of potentially working safely. This is why later generations of cobots produced by OMRON, among others, are not equipped with force sensors, but register the power consumed by the servomotors in the axes. This makes the system's operation somewhat rougher, but it also makes the system cheaper, and therefore more attractive commercially.

In addition, major progress has been made in relation to the user interface. The first KUKA robot still had to be programmed using traditional methods, but in recent years the interface has been simplified such that it is possible to work with the cobot after just a few days of training. Together with cheaper technology this has contributed to the tremendous growth in cobot sales. Since the sale of the first type of cobots in 2008, 22,000 cobots were sold in 2020 alone. Since 2008, the share of cobots has grown from 0% to 5.72% of the 384,000 robots sold throughout the world in 2020 (IFR, 2021b).

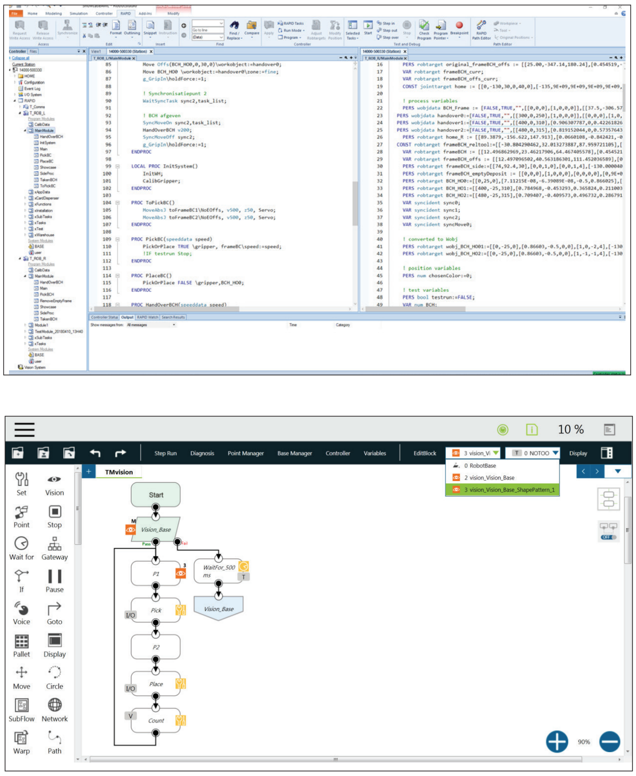

Figure 3:

Examples of programming collaborative robots. Above an ABB YuMi, under an OMRON TM12 (OMRON, 2018, p. 117).

1.2.2.2 Smaller series with greater variety

Due to their user friendliness, cobots are less expensive to program. This also makes it more attractive to automate smaller series. Due to the variety of the parts to be produced this is also of benefit: if the program logic, such as interrogation requests and control of inputs or outputs, is already in place, a program can relatively quickly be converted to handle similar products. This is because a cobot can be relocated by hand and a mistake does not have immediate disastrous consequences for the cobot, because it has been built to monitor unintentional external forces and to act accordingly.

1.2.2.3 Safety-related paradox

Its name and its user friendliness, however, result in a paradox that still is not being addressed effectively. Although cobots derive their name from the fact that they can be used collaboratively due to their ability to monitor external forces, this does not automatically mean that they can be safely deployed in support of any process. For example, a cobot may have an impact on a person, but the permissible impact is dependent on the body part that may be impacted and the type of impact – jamming or pushing away.

Automating a welding process, for example, requires more safety than simply deploying a cobot (Vrugteveen, 2020). For example, a jolt to the torch can easily exceed the maximum permissible impact, and welding light forms an omnidirectional hazard that can create 'flash eye' in bystanders. Let alone the currents used while welding metal and the temperatures this creates.

To be able to safely deploy cobots in more hazardous processes it is necessary to implement safety measures. This can be achieved by locally screening processes or by replacing them with other similar processes. However, in case of welding this is not really an option.

In spite of this, the user friendliness of cobots counterbalances the costs for the welding industry. With cobots, welders can contribute their process knowledge by manually placing the cobot on the product at the right fusion angle. The welding path must be completed with unprecedented precision – straight line or circular – and at a very constant speed and fusion angle. If the interrogation requests of safety sensors are safeguarded in the background, these benefits can quickly outweigh the drawbacks.

1.2.2.4 Cobots mounted on a pedestal

In the welding industry cobots are primarily mounted on a pedestal. This only requires investment in the welding equipment and pedestal. In many cases companies cut back on safety. Often to such an extent that the installation becomes unsafe. For example, when:

- the cobot, because of programming freedom, can make any movement at the speed entered. This ignores the type and degree of impact as set out in ISO/TS 15066:2016, the safety standard for collaborative robots;
- the cobot's welding startup is indicated by a signal lamp or a buzzer. The signal lamp is ho wever not visible through a welding mask and the buzzer is inaudible due to otoplastics;
- there is danger to a welder working adjacent to the cobot. The welder will then have to shut down the cobot. However, the stop button is not always located in a logical spot for the person in question.

More elaborate versions are also available whereby safety is secured through means of a dead man's switch or welding screens. This requires higher investment, however, and not every company is prepared to make this investment.

Figure 4:

A common application of a cobot in the welding industry – the pedestal-mounted cobot. This AWL version is equipped with a dead man's switch to safeguard the safety of bystanders.

Figure 5:

A cobot welding cell. This version – AWL's Qube – is equipped with a manually operated turntable at the front and a cobot within the protected area.

The cheapest option of the two is the dead man's switch, whereby the operator holds a button in his hands that he can hold in three positions: with open hand, with a fully closed hand or at a controlled midway position. The cobot can only weld when the button is held in the controlled midway position. This mechanism anticipates the fight or flight instinct: in case of an emergency situation the person holding the button is startled and depresses the button or lets it go.

In case of light screens, a safety switch must also be used. In this case the cobot must only be allowed to weld when the screen is closed. If the screen is open, the cobot is not allowed to weld. If the screen is opened during welding, the cobot must stop immediately. The investment for this is higher, but the advantage is that the operator can also do other things while the cobot is welding. Nonetheless, due to the closed screen it is impossible for the cobot and the operator to be at the pedestal at the same time.

1.2.2.5 Workers prefer cobots

Robots increase a company's vitality, as do cobots. However, research shows that workers prefer cobots (Meissner et al., 2020). A robot cell provides opportunities for personnel with secondary or higher education, because they make themselves indispensable to the company when they devote themselves to programming robots. Paul de Beer, Professor of Labor Relations at the University of Amsterdam, for example emphasized this in an interview as part of his research into the impact of robotization on the quality of work (Malowski et al., 2020b).

1.2.3 The robot cell and pedestal-mounted cobot hybrid – the cobot welding cell

Robots and cobots both are suitable for automating welding tasks. Because of the costly programming, robots are only cost effective for larger series with little variety. Cobots are easier to program, which makes it easier to produce series with greater variety that are profitable. Because cobots cannot work at the same time as the operator and because they are slower than robots, robots overtake this option as the size of the series increases.

There is a gap between the smaller series and the large series. In this gap, the cobot's hourly production capacity is in fact too low, while the investment in the robot is still too high. An ideal solution to this dilemma may be a mix of both: a cobot welding cell.

1.2.3.1 Small to large series, low to high variety

A cobot welding cell in fact is a robot cell that contains a cobot. The cell consists of a safe airtight protective enclosure that protects the operator against collisions and direct welding light, with a turntable at the front where operator and cobot can work with the machine at the same time. By having a cobot inside the cell, the labor-intensive programming process is replaced by the user-friendly programming of the welding positions, that the welder can teach the cobot him/herself.

Because the cobot welding cell is equipped with a turntable, the operator and the cobot are able to work with the machine at the same time: the cobot welds on one side of the turntable, while the operator can remove the welded products and load new product parts on the other side. This makes it possible to almost double the number of products produced by the cobot welding cell during each cycle in comparison to a pedestal-mounted cobot.

The flexibility of a cobot welding cell can be applied in multiple areas. Cobot welding cells are stand-alone and only weigh 1.5 metric tons, which means they can be freely located or relocated anywhere within the factory with a forklift truck or an overhead crane.

The turntable is a pedestal on a rotating shaft. The pattern of holes in the table facilitates rapid conversion between different products. In case of products that are produced more often, it is also possible to make a template with holes at the corners that can be quickly interchanged on the table. If the table is not wide enough, it can also be expanded somewhat by attaching clamping blocks at the sides or front of the turntable. This makes it possible to expand the rectangular 1200mm x 550mm (W x D) turntable into virtually half a table with an 850mm radius – the maximum width at which the table can still be rotated within the wall panel.

The product variation supported by a cobot welding cell goes well beyond the simple programming performed by a welder. When a product is produced more often, the corresponding program can be retrieved when necessary. In addition, the cobot can be programmed to allow for flexible loading: the same products on both sides of the table, different products on each side and multiple products on each side.

1.2.3.2 Economically profitable

Ranging from least to most expensive, the above-mentioned automation options are as follows:

- Pedestal-mounted cobot
- Cobot welding cell
- Robot welding cell

The cobot welding cell is more expensive than a pedestal-mounted cobot due to the additional hardware and electronics that are required. In some cases, the hardware for a robot welding cell is cheaper. However, specialized programming experience – which is not self-evident – is required to be able to work with the robot welding cell. One option is to acquire this knowledge in-house, but that is a luxury not everyone can afford. Another option is to purchase the production process from an external party, which quickly makes this an expensive investment, more expensive than a cobot welding cell.

The price of AWL's Qube (AWL, 2020) will be used as the reference point for the cobot welding cell.

To provide for a fair comparison, this price is compared with the recommended prices of similar alternatives from other suppliers. That means: the same type of pedestal, welding equipment and – in case of the pedestal-mounted cobot – the same cobot. The following reference pricing then applies:

- Pedestal-mounted cobot: €65,000
- Cobot welding cell, AWL's Qube: €100,000
- Robot welding cell: €200,000

If the pedestal-mounted cobot were to be used for a single full shift each working day, the investment would be recovered within 26.3 months. Assuming the same level of use, an investment in a Qube would be recovered within 23.3 months. However, the payback time of a robot cell with the same level of use is generally 36 months.

	Certified Manual Welder	Pedestal-mounted Cobot	Cobot Welding Cell
Investment	€0	€65.000	€100.000
Type of laborer	Certified Manual Welder	Operator	
Average hourly laborer costs in the US in 2022	€34.67	€26.64	
Monthly payback per shift that the cobot welding cell is used compared to manual welding	-	€2,879.77	€4,974.67
Payback period when using 1 shift per day	-	26.3 months	23.3 months
Payback period when using 2 shifts per day	-	13.2 months	11.6 months

Table 1:
Calculation of the payback period for investment in a pedestal-mounted cobot and a cobot welding cell. This is compared to the situation in which a certified manual welder is employed.

However, the payback period is only part of the comparison. On average, a Qube is 45% more efficient than a pedestal-mounted cobot and a robot welding cell is 50% more efficient. A cobot welding cell and a robot welding cell are both equipped with a turntable, but a robot welding cell generally is somewhat faster. This is in part due to the robot's higher speeds of movement and the savings in cycle time due to the automated clamping tools and the turntable.

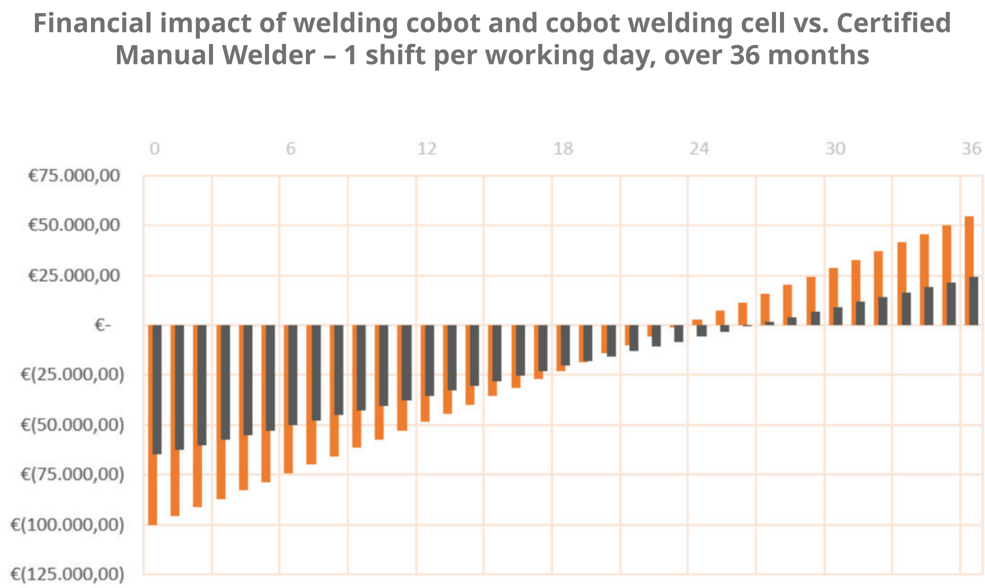

Figure 6:

Graph of the payback period for an investment in a pedestal-mounted cobot (dark grey) and a cobot welding cell (orange) in comparison to a certified manual welder. Vertical axis: financial impact; horizontal axis: number of months after investment.

This therefore means that a cobot welding cell can produce 45% more products than a pedestal-mounted cobot within the same period.

Suppose that the same number of products per year is produced by the pedestal-mounted cobot and the Qube. The breakeven point at which the Qube is cheaper than a pedestal-mounted cobot is 19.3 months. This is even before the cheaper pedestal-mounted cobot has paid for itself. The reason why the Qube overtakes it, is because of its higher efficiency.

1.3 Conclusion

The welding industry has been growing year after year, even during the global pandemic. This growth is expected to continue over the coming decades. On top of this growth, the variety of welding work is also growing as a result of the further rollout of mass customization beyond the automotive and fashion industries.

The welding personnel needed to absorb this growth and diversification as yet does not exist. Moreover, the gap between the demand for and the available supply of welders is growing every year due to the strong growth of the welding industry, as well as the significant number of upcoming retirees. Steps will therefore have to be taken in terms of automation in order to achieve higher production levels with the same number of people.

Automation in the welding industry is generally achieved by means of robots. These are located in a cell and are really only profitable for production series in the tens of thousands of units per year. In addition, they are not cost-effective due to the high investment required and the lack of flexibility in the programming associated with these robots. Cobots lower the programming threshold, which makes them attractive for flexible production. However, due to practical and safety reasons, the frequently seen pedestal-mounted cobot is unable to achieve production numbers with the efficiency of a robot welding cell.

A welding cell implemented with a cobot – a cobot welding cell – offers the best of both worlds. The cobot offers the possibility of effectively and easily converting the programming for different products. The cobot welding cell with a turntable increases efficiency by as much as a factor of two in comparison to a pedestal-mounted cobot. The investment is higher than a pedestal-mounted cobot, but significantly lower than a robot welding cell, especially when the experience required to program a traditional robot is factored into the equation. The combination of a higher price with higher efficiency means that a cobot welding cell can have a payback period that is shorter than that of a pedestal-mounted cobot.

As a result, the cobot welding cell is the most efficient, and from a pricing perspective the best option for absorbing the growing demand and variety in the welding industry. Welders will no longer need to do series-oriented work, which can now be done by the operator after a welder with his/her knowledge has programmed the cobot to produce the product.

Contact

For more information about the cobot welding cell see: awl.nl/qube

Questions about this article? Ask Tom.

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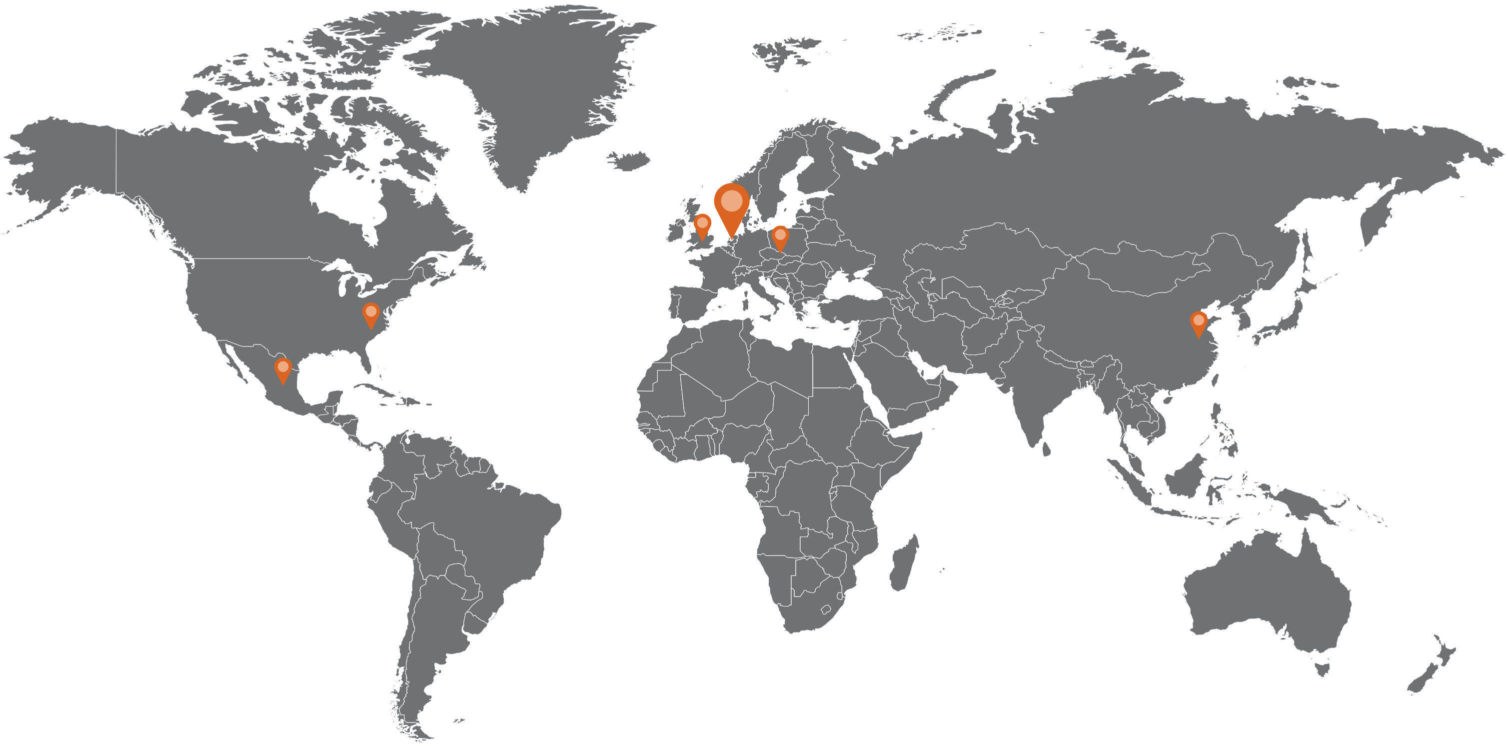

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