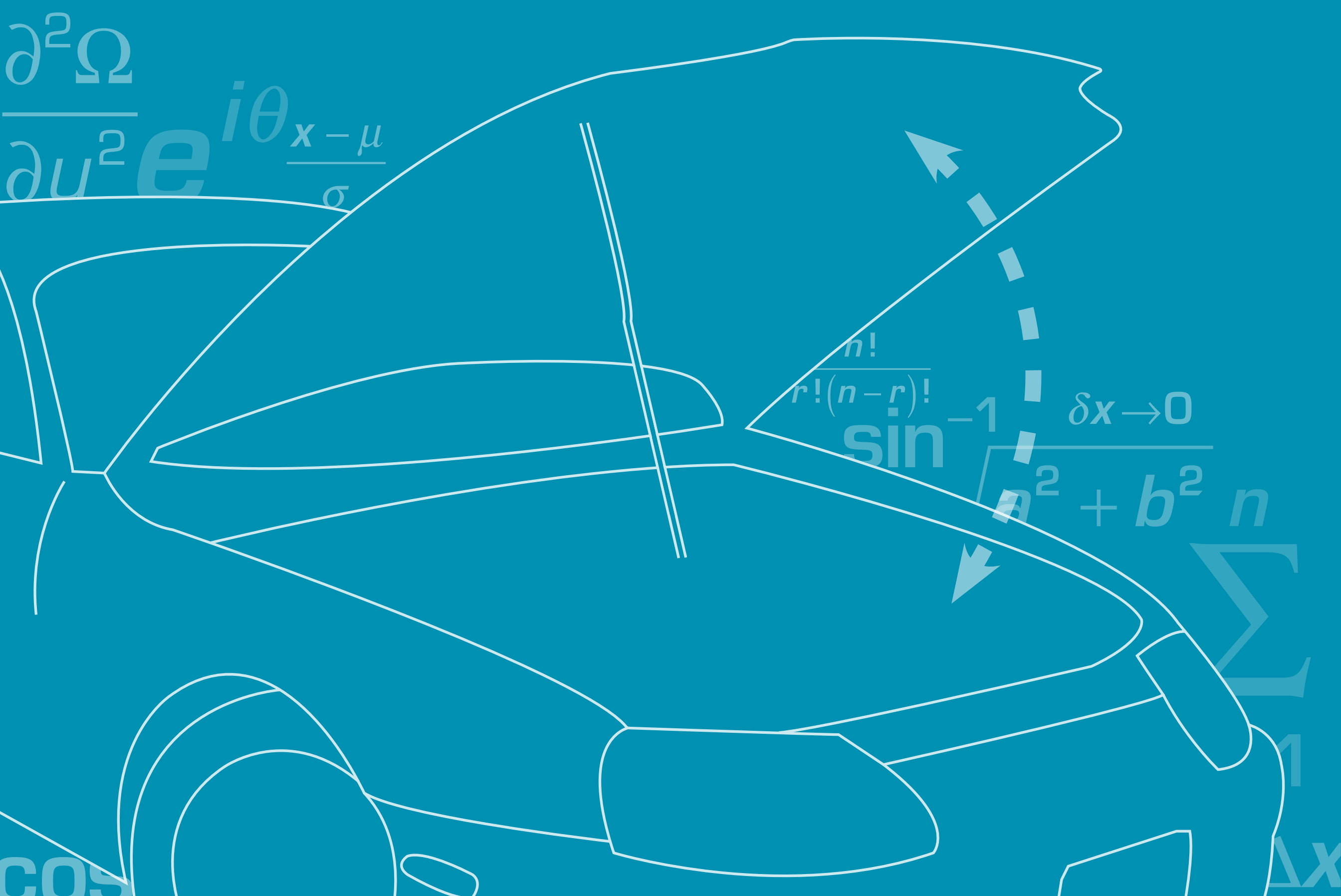
Achieve

mathematics at work

Manufacturing



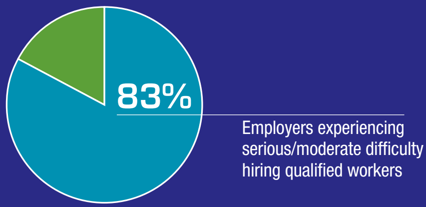
Mathematics in the Manufacturing Sector

The manufacturing industry has changed dramatically over the last two decades. The sophistication and skills needed for success in the workplace today mean that employers place a premium on the ability to apply mathematical knowledge to solve problems. An education system that provides students with the quantitative knowledge and skills for translating information represented in different formats — coupled with the ability to engage in critical inquiry and problem solving — will be what keeps the skilled manufacturing industry in the United States on the cutting edge.

Available Manufacturing Jobs

Within the advanced manufacturing industry, there are a variety of entry-level jobs that pay well and provide opportunities for advancement — jobs for high school graduates with postsecondary training or education but less than a four-year college degree. Individuals who participate in some form of postsecondary training — be it on the job, in a training center or at a community college — are often even better positioned to succeed in the manufacturing sector. Some employers and industries may require specialized training or education beyond a high school diploma. In addition to motor vehicle production, other leading manufacturing industries with good job opportunities include semiconductor and electronic components, aerospace products and parts, and architectural and structural metals.

A Growing Skills Gap of Qualified Workers



Source: Manufacturing Institute, *2011 Skills Gap Report*.

Core Mathematics Knowledge in Today's Manufacturing Jobs

Developed by secondary, postsecondary, business, industry and government leaders, the national Career Cluster Pathway Plans of Study for *Production* and *Manufacturing Production Process Development* recommend a set of rigorous mathematics courses for students to take at both the secondary and postsecondary levels in traditional or vocational settings to pursue a career track in manufacturing. These Plans of Study show in detail how the foundation provided by courses such as Algebra I, Geometry, Algebra II, Trigonometry or Statistics, Computer Applications, and Applied Manufacturing Technology equips high school graduates with the mathematical knowledge and skills needed for success on the job. Until high school graduates understand the advanced mathematical skills used in the manufacturing sector, they will remain unable to meet the demands of this high-growth industry. For more information on the Career Clusters Initiative, see www.careerclusters.org/resources/web/pos.cfm.

Jobs	Median yearly salary	Percentage of total jobs by education/training (ages 25–44)		Number of total jobs		
		High school	Some college/ associate	2010	2020	% change
Electrical and electronics engineering technicians	$56,900	23%	56%	151,100	154,000	2%
Mechanical engineering technicians	$51,400	23%	56%	44,900	46,700	4%
Installation, maintenance and repair mechanics	$36,700	40%	34%	143,600	160,300	12%
Engine assemblers	$36,400	53%	31%	33,700	35,500	5%

Source: Bureau of Labor Statistics, U.S. Department of Labor, *Occupational Outlook Handbook, 2012–13 Edition.*

The Common Core State Standards: Ensuring College and Career Readiness

The Common Core State Standards (CCSS) are K–12 mathematics and English language arts/literacy standards that identify the academic knowledge and skills all students need when they graduate high school to be ready for their next step, be it college, the workplace or the military. The CCSS were developed through a process managed by the National Governors Association and Council of Chief State School Officers and led by states. To date, more than 40 states have chosen to adopt and implement the CCSS.

In mathematics, the CCSS include focused content standards as well as Standards for Mathematical Practice, which articulate the ways students should apply mathematics both in school and on the job — to solve problems, reason abstractly and quantitatively, critique arguments, model, exercise precision, and look for repeated reasoning. In English language arts/literacy, the CCSS include expectations for reading, writing, language, and speaking and listening, including students' ability to work in teams and communicate effectively in a range of settings.

The CCSS are anchored in college- and career-ready expectations, which start in grade 12 and are back mapped to the earliest grades. Students who graduate from high school having mastered the CCSS will be academically prepared for college-level courses and rigorous career training programs. Importantly, the CCSS represent the floor, not the ceiling, and students should engage in additional coursework and work-based experiences to help chart their career pathway.

The CCSS can be found at www.corestandards.org.

"Mathematics at Work" Series

First developed in 2008, using the American Diploma Project benchmarks as the foundation, Achieve produced a series of "Mathematics at Work" brochures to examine how higher-level mathematics is used in today's workplaces. Updated in 2013 to reflect the expectations set by the Common Core State Standards in mathematics, the brochures present case studies drawn from leading industries nationwide to illustrate the advanced mathematics knowledge and skills embedded in jobs that offer opportunities for advancement and are accessible to graduates with some education and training beyond high school but less than a four-year degree.

The series underscores the value of a rigorous high school curriculum in mathematics. All high school graduates — regardless of whether they enroll in college, join the workforce or enter the military — benefit from acquiring a college- and career-ready foundation in mathematics.

To view or download the full set of "Mathematics at Work" brochures, go to www.achieve.org/math-works-brochures.

Mathematics drives

Career Preparation for Multiskilled Employees on the Toyota Production Line

Manufacturing companies like Toyota recognize that the most effective and productive line employees are multi-skilled workers who have a sophisticated understanding of electrical and mechanical design as well as fluid power and fabrication applications. Toyota, in fact, has found that the single most important asset possessed by their most talented multiskilled employees — many of whom have only a high school education and some additional training — is a strong foundation in mathematics that is applicable across all manufacturing fields.

Over the years, Toyota has streamlined its training program to maximize its effectiveness so that new hires work through a rigorous sequence of job training courses in only those areas where they lack sufficient background. Many of the courses teach concepts covered by the Common Core State Standards in mathematics. Key courses include:

- Math Refresher (e.g., computing with rational and real numbers, basic operations with algebraic expressions, modeling, right-triangle trigonometry)
- Electronics (e.g., manipulating linear equations, advanced physics, amplitude and phase shift for sine and cosine)
- Machine Structure (e.g., output-input power, graphical representations of data)
- Fluid Power (e.g., Pascal's law)
- Metric System (e.g., units and measurements: length, mass, time, temperature, pressure and torque)
- Blueprint Reading (e.g., Cartesian and polar coordinates)

The capstone course for manufacturing trainees is Troubleshooting. In this course, technicians must be able to draw on all of the mathematics, physics and engineering concepts they have learned to solve real problems drawn from the factory floor.

Solid mathematics is not the only skill needed to be successful at companies like Toyota. Although the specifics of the technical work may vary from team to team, all skilled line employees are expected to be able to articulate and communicate the complexity of a project, translate their understanding into the language of mathematics, and work together as a team to arrive at the most practical and effective solution to the task at hand.

Integrating their understanding and putting it to work is just the beginning, as employers know that change is just around the corner. Hiring knowledgeable employees and equipping them with the training they need means that companies in the manufacturing sector will be able to compete today and adapt to the technological needs of tomorrow.

> *"Good math skills will improve your chances of getting a job with Toyota, improve your chances of getting a higher-paying job, improve your chances of being successful on the job and improve your chances of moving up in the company."*

Bob Tribble, Team Leader
Toyota Paint Operations

Painting by Numbers: Mathematics in Action on the Toyota Production Line

Cobalt blue, cherry red, midnight black — Toyota's cars come in these and 26 other colors. Transforming the steel frame into the sleek car of tomorrow requires — among other tasks — opening the hood during painting. Creating a machine that automates the process and can be adapted to future car designs was the challenge — but would the design team made up of line workers be up to the task?

The goal was to build a hood opener with a lift arm to hold the hood in place while a technician installs a stabilizing monster jig — the device that keeps the hood in the correct position — prior to painting. The hood opener needed to follow along with the car, complete its task and return to home position in less than a minute. And it needed to operate safely more than a thousand times a day and last for at least 10 years — a long time frame that would allow the hood opener to be adaptable to subsequent model changes and new car designs.

Designing from the Ground Up

Mathematical Reasoning, Problem Solving and Teamwork

The hood opener design team consisted of a group of skilled employees who had expertise in welding, machining and electronics — but were not engineers. During the initial design phase, they needed to outline the function the hood opener would perform and determine how it would be powered.

They determined that the hood opener would be suspended from a track above the production line and follow the car as it neared completion. The lift arm would extend and contract to grab and raise the hood, and then it would release the hood once the monster jig was in place. The team compared the advantages and disadvantages of using electricity, hydraulics or pneumatics to propel the hood opener. They decided against using an electric motor because it would be heavy and cumbersome and could emit sparks. They eliminated hydraulics due to the potential mess and danger if a leak developed. Pneumatics — the choice of the team — are explosion proof and, provided the pressurized air is kept clean and proper lubrication is added, they have a long service life.

Putting the Pieces in the Right Place at the Right Time

Geometry, Algebra and Data Analysis

Coordinating the actions of the pneumatic arms required the design team to refer back to the formula for the proportionality of theoretical torque. By determining the torque that corresponds to motor displacement — and knowing the fluid density and gravitational acceleration — the design team determined the difference in hydrostatic pressure due to the weight of the fluid and built a motor for a smoothly operating yet durable lift arm.

> *"Any improvement in personal math skills is equivalent to a company improvement at Toyota."*
>
> Cheryl Berkley, Team Member
> *Toyota Assembly Operations*

After working through the mechanics of pneumatic arms, the design team next wanted to ensure that the hood opener would have the latest safety controls installed. Electrical circuitry would guarantee the well-being of technicians on the production line if the switches used were both efficient and fully operational. Together, the team checked the control circuits employed in the design of the lift arm using truth tables based on Boolean algebra to analyze their logical behavior and ensure that power would be delivered accurately and efficiently to specific parts of the circuit.

After running through the electronics, the team turned to measurements. How long was the hood? Where was the lip of the hood relative to the hinge? If the lift arm did not extend far enough, it would not connect to the hood properly. If the hood was raised too high, it could cause a premature release. If the hood was not raised high enough, team members would not be able to perform their job properly, and the hood could be damaged when released.

Basic right-triangle trigonometry was essential to the task of designing the lift arm, but the calculations were complicated by the fact that car hoods are not perfectly straight like the side of a triangle — and different hoods open to different angles. By considering several different locations for the hood opener, the team determined where to anchor the lift arm relative to a car as it traveled down the production line. The team created an all-purpose schematic so that, once the size of the hood was known, the length of the lift arm could be calculated. Its length depends on the initial and final angle of the hood as well as the position of the lift arm in the ceiling mount and is designed to allow the hood opener to work with any type of car.

20 Years and 6 Million Operations

It has been more than two decades since the design team — armed with a diverse array of high school mathematics skills — built and installed the hood opener. But through numerous new car designs and more than 6 million operations, the lift arm is still working safely and effectively. That is mathematics at work for business.

Mathematics + Teamwork = Success

Companies like Toyota expect all of their technicians to have a strong foundation in mathematical knowledge because the most productive and skilled workers are those who can apply mathematics in a wide variety of situations. The application of such mathematical skills is evident in the successful design of the lift arm at Toyota. The team consisted of line workers — high school graduates with some postsecondary training — and relied on their understanding of many mathematical applications, including calculating proportions and scale factors; modeling and solving linear equations such as Boyle's Law for ideal gases; measuring using various units in different systems; calculating with integers, fractions and decimals; and reading and presenting data in charts, tables and other graphic displays.

The team also relied on coordinate geometry and trigonometry to be able to describe the location of the point of support of the hood and how to position the lift arm for different types of vehicles. In addition, the control circuits employed in the design of the lift arm required knowledge of Boolean algebra and propositional logic to understand the truth tables involved.

Although the design of the lift arm relied on the mathematical knowledge of the team members, it also relied on their ability to work together. Indeed, research by Achieve and others shows that both in the college classroom and in the workplace, professors and employers identify collaboration and communication as important factors for success.

At Toyota, teamwork and communication skills have always been at the core of its business — but as the global marketplace increases competition, today more than ever Toyota relies on employees who can collaborate and work together to keep the company on the cutting edge. Regularly, Toyota expects its employees to provide ideas and solve problems to improve the manufacturing process. The company actively seeks out workers with foundational mathematical knowledge and provides training to build or reinforce their ability to share information and cooperate on projects.

The focus of leaders in the manufacturing sector reinforces the importance of ensuring that students graduate from high school with the academic knowledge and skills they need to succeed in jobs that pay well and offer opportunities for advancement. For employees to succeed at Toyota — or elsewhere in the manufacturing industry — they need higher-level mathematics knowledge and skills as well as the ability to communicate and problem solve — skills that also are included in the college- and career-ready Common Core State Standards in mathematics and English language arts/literacy.

> *"At Toyota, math is so foundational to all of our work — in machine maintenance, on the production floor, in the office — that it's inseparable from that work. Without effective math skills, one cannot be an effective Toyota worker."*
>
> Dennis Dio Parker
> *Toyota North American Production Support Center*

About Achieve

Achieve, created by the nation's governors and business leaders, is a bipartisan, non-profit organization that helps states raise academic standards, improve assessments and strengthen accountability to prepare all young people for postsecondary education, careers and citizenship.

About the American Diploma Project (ADP) Network

In 2005, Achieve launched the ADP Network — a collaboration of states working together to improve their academic standards and provide all students with a high school education that meets the needs of today's workplaces and universities. The ADP Network members — responsible for educating nearly 85 percent of all our nation's public high school students — are committed to taking four college and career readiness action steps:

1. Align high school academic content standards with the demands of college and careers;
2. Establish graduation requirements that require all students to complete a college- and career-ready curriculum;
3. Develop statewide high school assessment systems anchored to college- and career-ready expectations; and
4. Create comprehensive accountability and reporting systems that promote college and career readiness for all students.

The world has changed, and high schools must change with it. The ADP Network is leading the charge in ensuring that all high school students graduate with a degree that works.

For more information about Achieve and the ADP Network, visit www.achieve.org. To view additional "Mathematics at Work" brochures, visit www.achieve.org/math-works-brochures.

Achieve ■ 1400 16th Street NW, Suite 510 ■ Washington, DC 20036 ■ www.achieve.org

Editorial assistance and design: KSA-Plus Communications