THE MAKER MOVEMENT MANIFESTO

RULES FOR INNOVATION IN THE NEW WORLD OF CRAFTERS, HACKERS, AND TINKERERS

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Knowledge, Learning, Control, and Intelligence

"Hi, Mark, I want to introduce myself, I'm David Lang," David introduced himself. We were upstairs in Tech-Shop's San Francisco location.

"Hi, David," I said, extending my hand. "Nice to meet you, too." I looked around. "So, what are making?" My favorite question.

"Well, nothing yet," David replied. "I'm just getting ready to take some classes. I wanted to talk to you to make sure that it would be okay if I wrote about my experience here. You see, I don't know how to make anything, and I want to become a maker. I convinced *Make:* magazine to let me write a column on my experiences while becoming a maker. I'm calling it 'Zero to Maker.' I just need to make sure it's okay with you guys if I document what I'm doing here."

"What a great idea! Of course we'd love to have you document your journey. What's your first class?" I asked.

"One of your Dream Consultants suggested I start with the laser cutter. I'm taking that class tonight."

"Perfect," I said. "We call that our 'gateway drug' because it's powerful, easy to use, and extremely addictive—all the things a pusher needs in a gateway drug to get someone hooked." I paused. "So, what *is* your background?"

"Oh, well, my last job was chartering sailboats. The most complicated thing I've ever created was a really good e-mail."

We both laughed.

"I quit that job, and I'm trying to remake myself as a 'maker,'" David added. "Or at least start the journey while I look for other work."

A couple of months later I read his first columns on the *Make:* blog site. I learned that David had joined with a friend, Eric Stakepole, who had started an OpenROV project. "Open," as in "open source," a strategy where in exchange for publishing all the specifications of a project and creating a license where anyone can use the results, people from all over the world contribute time, energy, insight, and money to develop a project. "ROV," as in "remotely operated vehicle." The purpose of this project: to design a robotic submarine that would make DIY underwater exploration possible for everyone. Wow, I thought, zero to ROV is pretty ambitious.

Ambitious or not, David and Eric are making an ROV company. And David is no longer a maker newbie. In the time since we first met, he has taken over 20 classes and visited our space more than 200 times. The OpenROV Kickstarter campaign raised over $110,000, and David now has two jobs—writing for *Make:* magazine and working at *his* company with Erik—and a book project, *Zero to Maker*, which he also crowdfunded on Kickstarter.

(Kickstarter is a "crowdfunding" website where people like David post their project ideas and the "crowd"—often friends, family, and Facebook friends—sponsors the project by pledging money through the site. If enough people pledge enough money, the project gets funded. More on Kickstarter later in the book.)

KNOWLEDGE

The creation, development, and distribution of knowledge are interesting things. Whether you want it, need it, or have it already impacts what you know as possible. But wanting it is key. Creating an engineer or a chemist takes time.

When I say "knowledge," I'm talking about the deep knowledge that comes from both book knowledge and knowledge that comes from experience Often knowledge developed through our experience is what encourages us to go back to the book to figure out what is happening. Here are a couple of examples:

A TechShop staff member recently observed, "You know, until you try to mill stainless steel, you really don't understand how hard it is."

What was interesting about this statement was that the staff member had taken the "strength of materials" class required for a mechanical engineering degree, yet he had not experienced it viscerally.

John Seely Brown, former CTO of Xerox and PARC, Xerox's famed research lab, once came to TechShop and told us that many children learn "through their bellybuttons." I love the description. This staff member had just learned through his bellybutton. Hands-on discovery is an important part of knowledge development and a key creator in sparking a desire to learn.

For example, I wasn't very interested in materials strength until one day in Special Forces field training a demo man demonstrated how to blow a hole through a block wall. I was fascinated.

"How did you know how much to use to blow a hole, but not blow up the entire wall?"

He showed me the formulas he used for walls, reinforced or not, bridges (steel, wood, concrete), and the characteristics of different types of charges and explosives. All of a sudden, I was interested in physics. Who knew?

Likewise, I once asked my high school chemistry teacher what had hooked him on chemistry. His reply? "Sodium."

It turns out that pure sodium burns on contact with water. Back in my teacher's day, sodium was easier to get, so he got some. Then he sprinkled it on his neighbor's yard so that mini-volcanos of fire would erupt when the sprinklers were turned on. (Don't try this at home!) He was hooked for life.

Finally, I was at a high-tech conference years ago populated by senior executives from computer software and hardware companies when the speaker asked everyone who had been "the film projector tech guy in school" to raise their hands. Given that only one or two of those people were needed in each room in sixth grade, but that we would probably over-sample, I figured half of the people in the room would raise their hands. Surprise: Every hand was raised. The same was true for, "Who played extensively with LEGOS?" Some folks raised *both* hands on that one. The play value of LEGOS was so visceral that they wanted to give it an extra vote.

True knowledge is born through experience. You have to physically bore into the details of something to fully understand it. Hands-on discovery and exploration are required to innovate. Mastery is required, time is needed—a class on materials is not enough; you have to spend time experimenting in the lab or in the field. True, deep knowledge is hard won and comes with experience.

INFORMATION

We live in the information age. Google and Wikipedia answer our questions. Khan Academy, Apple U, and, increasingly, major universities put their courses online for anyone to find and use. You can teach yourself just about anything now for the cost of a computer and your time. You might not get a degree or certificate vouching that you know it, but the raw information is there for the taking.

Interesting things happen in a world where information is free, easy to obtain, and ubiquitous. The biggest is *transparency*: Everyone knows how much Best Buy wants for the latest gizmo. It's posted online. You can shop Amazon, Craigslist, Best Buy, and hundreds of other merchants right now from your cell phone. There are no longer sunk costs in driving down to the store or mall to find out what an item is selling for. This is "friction" free information: pricing information is available when you want and need it, and you don't have to pay anything for it. This information falls into the category of "search and find costs." In the past, search and find costs were very high and led to suboptimal purchases—seriously expensive suboptimal purchases.

There are two sides to a sale, though. It isn't just that the consumer is trying to find a store; the store is often trying to find the consumer. So the search and find function works both ways. As you've probably experienced, you can save a lot of money by shopping online and finding the thing you're looking for cheaper from an online store. This is true for a lot of purchases, not just consumer purchases.

During the dot-com craze in 2000, as this friction-free flow of information was just starting make itself felt, I was at a firm that needed an animated logo—a cartoon. So we searched through our Rolodexes for a few design firms we knew that could do this kind of design. We also posted the project on an online job board. Through the traditional methods, we received a number of inquiries and bids in the $20,000 to $40,000 range for the work. But because we had posted the project online, we also received some tremendous bids from lots of smaller players, independent designers, cartoonists, and even a couple of traditional firms. We also, and this is a big "also," got an inquiry from a local artist who had been looking to branch out a little and experiment. He liked the idea of working with a start-up. He agreed to do the job for about $5,000. Not bad, but not cash—he wanted stock. *Great*. Cash-starved start-ups have stock, not cash.

Now, many of you are going to think, and rightly, "So what? You saved some money on the Internet. Big deal." What I failed to mention is that this was an internationally renowned, Pulitzer Prize–winning cartoonist.

So let's review. This result exceeded all possible imagined outcomes—by a very, very big margin. The likelihood of getting a great design had just gone through the roof. The outcome was better. It was faster—the artist lived within five minutes of our office—and it was most certainly cheaper: He did the work for stock. Better, faster, and cheaper than the old-fashioned way. Can you imagine reaching into your contacts manager and pulling up a Pulitzer Prize–winning *anyone*? Then asking that person to do some work for you on the cheap? For stock? And you want him or her to visit your place next week to review the ideas?

This is what friction free means: both buyer and seller get connected more quickly, cheaply, easily, and sometimes with profoundly better outcomes.

The Internet also helps to reduce "sacrifice." This is what a customer has to put up with in order to get his or her needs met. There are no perfect products, and because products have a specific utility designed into them, the designer has to make trade-offs. Alas, the tradeoffs aren't always what the customers like. The item's too big or too small, it's not the "right" shade of red, it doesn't match other accessories, it comes with a limited warranty, or you need more of it than the seller has.

Take, for example, a simple No. 2 pencil. This should be as close to a perfect product as there is. It's ubiquitous, cheap, and it's been around for ages. It's made of simple materials—wood, graphite, glue, and a little metal band holding the eraser. Until I tried to understand the concept of sacrifice, I had never looked at a pencil particularly closely. It's a pencil. But think about it. Do you like the scratching sound it makes when it writes? I don't. Do you like sharpening it? Why do we have to do that? The eraser doesn't actually work very well, and it's not big enough. The graphite breaks too often. The line width is inconsistent as the tip gets dull. The graphite smears and gets on my hands. It's a really yucky yellow. It doesn't taste very good when I chew on it. Hey, I chew on it. It should taste like cherries. It doesn't have a cap for when I put it in my pocket. It isn't very strong. It's either too long or too short; I like mine midsized. I have to throw it away before I use all of it. I have to carry a sharpener. It makes a mess when I sharpen it. I waste graphite when I sharpen it. It's not legally binding when I sign documents with it. It isn't classy. When was the last time you proudly pulled out a yellow no. 2 pencil? It's just a pencil.

How much customer sacrifice do we put up with in other areas? Lots. One of the things that the Internet does is enable producers and consumers to better match with one another. If you think about that for a little bit, you begin to expect to see more producers selling fewer items today than you did before. And you would be right. I was thrilled to run across this gem of research from the Social Science Research Network because it proved that this is in fact what is happening. The Internet has changed the landscape of what is and what can be sold:

> Amazon's Long Tail has gotten significantly longer from 2000 to 2008 and . . . overall consumer surplus gains from product variety at Amazon increased five-fold from 2000 to 2008.[1]

The term *long tail* has gained popularity in recent times as describing the retailing strategy of selling a large number of unique items with relatively small quantities sold of each—usually in addition to selling fewer popular items in large quantities. The long tail was popularized by Chris Anderson in an October 2004 *Wired* magazine article in which he mentioned

Amazon.com, Apple, and Yahoo! as examples of businesses applying this strategy. [2] Anderson elaborated the concept in his book *The Long Tail: Why the Future of Business Is Selling Less of More*.[3]

And this research was concluded before the most recent economic downturn when people started thinking more about what they bought. When one purchases less, less frequently, and with more purpose, one focuses more on those acquisitions and wants them to be more useful, better constructed, fabricated by local suppliers, with local materials, and to come with a story.

IKEA and furniture chains like Ethan Allen will discover they are dinosaurs in the next decade. Why would I choose furniture that comes in the wrong size, with the wrong finishes and limited choices, isn't customizable, isn't personal, and is constructed by someone I've never met? Particularly if I could download the basic designs, mash them up, make them mine, and have a local artisan produce them for me? IKEA may be able to manufacture it for less than the local artisan, but so what? There is so much customer sacrifice with the retailer's furniture that IKEA doesn't see and isn't positioned to capture, it makes me cringe. And any local artisan can match Ethan Allen's prices and make the furniture locally sourced, potentially from recycled material, and imbued with more meaning because you can get to know the artist, select the wood, and work with the artist on the design. What if *you* made the furniture yourself?

When I got "the" big promotion to senior product manager a couple of decades ago, my wife and I decided it was time to buy some "real" furniture. We purchased a gorgeous set from a high-quality national branded furniture company. We got plenty of furniture for the $12,000 we put on credit (and spent the next four years paying off), and for a solid year I felt good every time I came home and saw those beautiful pieces sitting in our living room. But now I get no psychic boost from the purchase. The furniture is still beautiful, well made, high quality; we are still satisfied with the purchase. But if I were to do it again, instead of buying the living room set, I'd make it myself at our shop with my wife, who has always loved woodworking but could never afford the tools.

True, this would be a serious investment of time. We would have to skip a lot of quality TV time. But we might make a vacation out of the adventure and get the kids involved—to build something together that we would cherish until our dying day and then bequeath with pride to our children. If you don't have the time to make the furniture yourself, you could find a local artisan through the Internet with whom you could collaborate. You would have input into the design of the furniture, and it would still be more meaningful than picking it up at a store.

One of the cool things is that CNC production capabilities will begin to increase an artisan's fabrication capabilities, allowing him or her to more effectively compete with the larger manufacturer by increasing the artist's productivity, and when that happens, everything changes.

Watch for IKEA or Ethan Allen to try to compete with this new ecosystem and to open up a "local" section in their stores and online catalogs. Watch for them to add more customization, local artists, and DIY sections where you can participate in the build or design process. They have to evolve, or, like the dinosaur, they will go extinct.

LEARNING

I've talked about knowledge and information in this chapter. Let's move on to learning. Classes, books, and online instruction accelerate the acquisition of knowledge, and the acquisition of knowledge is one of the many things that is driving the Maker Movement. Why? Because now one can rapidly pick up the knowledge needed to make something. Helping this is the development of software that makes it easier and easier to control machines, so there is less to learn.

The online universe is exploding with instruction. From Khan Academy to Lynda.com and Instructables, it's possible to learn calculus and what the third derivative is, how to code in Java or use Ruby on Rails, how to construct an electric guitar, build your first robot, or thousands of other projects—from the comfort of your own home, on your own schedule, and for a fraction of the cost and time investment of traditional classroom learning.

In the past, if you wanted to personally learn how to make something out of plastic using molding machines, you could choose the trade school and apprentice route, maybe a junior college, or go through a full four-year bachelor's degree in mechanical engineering (and risk not actually getting to use mills and lathes or an injection molder). Both of these could easily take years. Now, you would sign up for a few specific software classes (two or three class sessions), a couple of CNC classes (two or three class sessions) and an injection molding class (one class session). You would then have enough skills to at least get started—this month.

The New York City coworking space General Assembly started out as mostly a coworking space and has morphed into a coworking space with serious educational training opportunities attached. General Assembly teaches user interface design, software programing, and other cutting-edge training that prepares one for a job right now. Classes run in length from one night to eight weeks. General Assembly is about to launch intensive several-week-long training in technical areas for which U.S. universities will not be writing curriculum for years. This is relevant, rapid instruction from real-world practitioners.

At our shop, we impart the minimum amount of information learners need to operate a machine safely and move their projects to the next step. It's a focus on adequacy rather than mastery. We don't offer 12 weeks of instruction on anything. The reason educational and vocational courses are 12 weeks long has more to do with keeping kids off the streets and not competing for work and keeping educational institutions and teachers profitable than it does with content mastery. I love our educational institutions, but they are designed the way they are for many other things than just imparting knowledge at the right time in the shortest period possible.

You want to learn how to weld? You can go to a trade school and then apprentice for months or maybe years, or you can find a local community college that offers a 13-week course on welding basics. Alternatively, you can buy a welder, watch some videos, and fire up the welding equipment in your garage—and risk burning down your house. Or you can find a makerspace and for $60 learn to weld in a couple of hours from an expert.

You won't be a very good welder at the end of our two-hour safety and basic use class, but you'll know the basics of welding and how to operate the equipment safely, and you will weld something. The odds are very high that you will be able to produce useful things with even this little bit of welding experience. And with some practice—well, lots of practice—you can get good at it. Good enough to finish your project without spending 13 weeks in a classroom or spending a few hundred dollars on your own welder and then storing it for the next decade.

What else could you learn in a day? Basic woodworking, how to use a laser cutter or sewing machine, how to use a waterjet cutter to cut four-foot by eight-foot sheets of steel, CAD/CAM basics, concepts of computer numerically controlled (CNC) machines, the basics of 3D printing or vinyl cutting, powder coating, sandblasting, basic carbon fiber, basic electronics, or dozens of other things. Yes, it is possible to go through your own personal maker revolution in the next 12 weeks.

CONTROL

Computer numerically controlled (CNC) milling machines, along with 3D printers and other computer-controlled tools like that laser cutter, plasma cutter, and waterjet have remade manufacturing over the last couple of decades.

Beginning in the early 1950s at MIT with the first development of a computer-tape, automatically driven, numerically controlled mill, there has been a steady rise of the CNC machine. Moore's law has helped to drive down the costs of the machines and totally revolutionized the design profession. The day of the drafting table's demise was predicted as early as the late 1950s and early 1960s. It took a while, but computer design has won out over drafting. With that, the ability to copy, modify, and produce has become much easier.

At first, these machines were extremely expensive and hard to use. A user had to learn an esoteric scripting language called G-code to make anything. With the development of easier-to-use software tools like Autodesk Inventor and even easier-to-use software like Autodesk 123D Make, the universal accessibility of design tools for making things has become a reality. You don't need to program in G-code or even know how to spell it. Some of this software is free. There are also online libraries of files that make parts so you don't have to do much at all to get started.

The ability to design and develop something in 3D on a computer and then use various tools to produce it is stunning. With the development of computer cloud systems that allow users to tap into the power of networked computers on the Internet, the ability to do very powerful development is now at the fingertips of anyone with a computer and access to the Internet.

With more advanced tools like Autodesk Inventor, one can even model simulations, stress analysis, strength, wear, and functionality. Using a design software's materials library and a finite element analysis engine, it is possible to swap out different grades of steel or aluminum on the fly and rerun a 10-year wear simulation in minutes.

What has really changed the "control" aspect of innovation and creation or manufacturing in the last decade is a combination of the price and the increasing capabilities of software and enabling platforms. Until very recently, good computer-aided design software tool cost between $5,000 and $100,000. But not anymore. A TechShop partner, Autodesk, began making "consumer" grade versions of its software available free. This is the same core engine for which the company charges thousands of dollars. Sure, Autodesk has removed items like finite element analysis, but what does the average maker care about that? And if you really do need that, come in and use one of our computers; they have all the fancy, expensive software you need.

Just as wonderfully, free libraries of cool designs are popping up. Autodesk, through a website, is supporting a community of people uploading designs, and other sites support the open hardware movement and provide free designs. Thingiverse.com is great. You can download the files and modify them to meet your particular needs. Type “thingiverse unicorn” into your Internet search engine and go to the thingiverse.com site, and you’ll see half a dozen unicorn designs that you can print on a 3D printer or modify and then print.

The three most popular tools at TechShop are the laser cutter, ShopBot CNC wood router, and 3D printer, each of which can be learned in a couple of class sessions. Our members routinely launch new careers after learning how to use the laser cutter or ShopBot, and we save tens of thousands of dollars at each location we build out by using the ShopBot to build furniture for everything from our flat pack front desk to signage and storage bins. (Flat pack is a method of using flat four-foot by eight-foot sheets to build desks, stools, chairs, and tables.)

What has happened over the last couple of decades is that the stepper motors and computer chips that control CNC machines have become so powerful and affordable that they are now being attached to amateur-level machines. The software is getting so easy to use that it’s possible to go onto youtube.com or a software company’s website and watch an instructional video, or take a simple introductory class, and begin making simple things within a week. This kind of rapid productivity has never before been possible.

In the past, if you wanted a small nightstand with a relief of your children’s faces carved into it, you would have had to hire a craftsman to build it for you, or attempt to make one yourself, freehand. Now you can take some digital photos of your kids off your computer, run them through a filter to give them depth, convert them to woodcutting instructions for the ShopBot, and make the nightstand this weekend. At a maker-space, you can accomplish this with three classes to become familiar with the necessary equipment, some free software, and a little experimentation to make something that your children will want to keep for the rest of their lives.

The “control” aspect of this revolution is hard to over-estimate. At the national level, the U.S. government’s interest in advanced manufacturing as a competitive opportunity to bring manufacturing back to the United States is being driven by this capability. I’ll talk about that more in a coming chapter.

PERSONAL INDUSTRIAL REVOLUTION

The first industrial revolution started around the year 1760 with the invention of mass manufacturing machines. The tailor uprising in France that contributed to the French Revolution was a direct result of the understanding of the tailor guild that its members’ way of life—their control of the tools of production—was being taken over by mechanization. As the development of the industrial revolution went forward, opposition to the new realities of production developed, eventually with Marx developing the idea that the tools of production should be owned by the state, not capitalists. I would postulate that few people joined the communist revolutionary movements because they truly believed the state should raise children apart from their parents. People joined the party because they were losing control of their means of production. For thousands of years, people owned their own tools to accomplish their work. They produced with their hands and their tools. With the rise of industrial machines, it became too expensive for individuals to own the means of production, and average craftspeople began to lose control of the tools they used to produce and thus became laborers.

Improvements in driving these machines came through the introduction of the steam engine, the refinement of the steam engine (the by-products of which were water pumping systems that allowed miners to mine more deeply for coal and ore), and the birth of the modern steel movement. Electricity came along, possibly the demarcation for the beginning of the second industrial revolution, bringing with it lightbulbs and electric engines, and over a period 150 years life was truly revolutionized. There is a lot of debate among historians about the timing of the start of the industrial revolution, as well as if and when the second industrial revolution occurred. Prior to electricity, industrialization was driven primarily by steam. The old plants had huge conveyers transferring power around a plant. With the discovery of electricity and the invention of electric motors power was more easily distributed.

Eventually the industrial revolution was exported. Japan went through its industrial revolution much more quickly in the 1870s, followed by the rest of Asia, including India and China a century later. Each time, the cycle shortened until the industrialization of a nation could be accomplished in 10 to 20 years. But still, the tools of industrial revolution were confined to those who could afford them—namely, big businesses.

Then, in the 1960s and 1970s, the Japanese started to produce capital tools and drive down their costs. Right behind them, the Chinese came in and drove down the costs still further. Over the last 20 to 30 years, there has been a greater than 70 percent reduction in the price of just the basic mill and lathe. One can now get a good lathe from China for $5,000 or a mill for $10,000. This is expensive, but not beyond the reach of a small business. As a result, the tool and die industry in the United States has all but dried up with the combination of inexpensive tools and cheap labor from other countries.

In parallel with this trend over the last 20 years, computers have been following the well-known Moore's law wherein computers double their capabilities every 18 months while maintaining their price. Initially, they were very expensive. Attach a computer and software license to a milling machine, and you added $120,000 to its cost. In addition, the operator had to learn how to program G-code and the software that produced it, which typically took six months to a year, assuming one knew how to use a mill to begin with.

All this has changed. Computers have invaded the manufacturing floor. Instead of costing $250,000 to $500,000 for a CNC mill, it's now possible to purchase one for less than $20,000, including the software. This is still a lot of money, but if you use a membership makerspace that has one, you can have access to it for around $125 a month. In addition, the CNC software is getting easier and easier to use; I see people go from introduction to producing useful parts in less than a week. I believe we are on the cusp of a third industrial revolution. Chris Anderson has called this the "New Industrial Revolution." It is being driven by inexpensive access to easy-to-use and powerful computer-controlled tools, including the magical 3D printers. Access to a complete innovation lab like a fully equipped makerspace has dropped by four orders of magnitude. With the development of pay-by-the-month maker-spaces access to these tools are 1/10,000 of what it would have cost just 10 to 15 years.

I started this chapter with David Lang, someone who had never made anything, but who through classes and access acquired enough knowledge and experience to take a leading role in developing a robot company, David essentially went through his own personal industrial revolution in about 90 days. Not 150 years, or 30 or 10. Ninety *days*. Hello. People can now go through their own personal industrial revolution for hundreds of dollars, not millions, and they can do it in weeks, not years or decades. It is not unfair to call it a revolution.

I met Perrin Lam much the same way. He introduced himself to me by saying, “I just want to say thanks for opening here in San Francisco. My name’s Perrin, and I’m remaking myself.”

Perrin is an older gentleman, a copywriter by profession, with probably close to 40 years of experience. He had started out at a big ad agency decades earlier, worked on big brand, advertising campaigns, and eventually went to the client side. He ultimately ended up writing advertising copy for a major newspaper, where he had good long career until the Internet and Craigslist all but destroyed the newspaper business. That’s when I met him, about a week after he lost his job.

“Imagine my dilemma, Mark. I’m a 60-year-old newspaper copywriter. Who is going to hire me?” Not waiting for my reply, he continued, “I’m going to become a jeweler. I think that laser cutter can do just what I want it to.”

I recently ran into Perrin, and he was excited. It’s been a couple of years now, and he has begun to sell his jewelry to the local museum store market. When I ran into him, he was getting ready to attend the national museum store buyer convention to show off how he could customize jewelry to match the unique character or domain of the museum.

One of the great things about remaking yourself is that you don’t forget your other skills. Perrin’s website, business cards, and brochures absolutely sing. You see, he is a pretty good copywriter.

INTELLIGENCE

There is a great deal of interest in the concept of advanced manufacturing. This is a large and diverse topic. Most of the press coverage is focused on the 3D printer as it is the “new” thing (as much as a 25-year-old technology can be new), but the field also includes CNC, robotics, and software. Design software tools are getting sophisticated enough now that they will do failure and manufacturing analysis and make suggestions on how to change a design to make it more manufacturing friendly.

A truly intelligent manufacturing system would understand what you were trying to make and would know what manufacturing capabilities you had, the quality you were trying to achieve, the materials at your disposable, the cost constraints you were working with, and a range of other needs. It would then interactively help you to optimize the product you were trying to make within the constraints it was given. It would also provide a complete set of automated (or, more likely, semiautomated) instructions on how to manufacture it in a flexible manufacturing environment. If that environment were a highly automated manufacturing location, one could envision limited human interactions. That's the goal, anyway.

But let's keep going. Many components will come with smart sensors. I worked on a project years ago that envisioned a future in which parts would know how they were doing (if they were broken, cold, stressed, bent, etc.) and could signal when a problem was developing. Imagine a bushing in an automobile with a cheap sensor that, when deformed, would send out a signal that it was about to fail. It isn't hard to imagine, then, a whole series of events being kicked off that would ensure a replacement was made for you, staged, and ready for repair the next time you were at the dealership. Mind you, it isn't broken yet, just getting ready to break. And when the above problem is tied into an advanced, distributed manufacturing system, the part would be made on demand at the time of need. It might not be the exact same part—replacement parts are a big business for automobile companies, and the parts markup is huge. A car company also has to carry the inventory and distribution costs. The automobile company might make more money upgrading the part slightly so that it could be made locally on demand.

I could see internal plastic components being laser sintered out of aluminum as a "cheaper" solution that is actually better from the consumer's perspective. Again, a typical new replacement part is three times as expensive as the original part integrated into the automobile because of all the carrying costs associated with it. Also, you can't always get just the part you need. I replaced an entire handle system on a car recently because a plastic piece broke, and I paid over $300 for the parts and $100 for the labor. Milling the piece out of solid stainless steel might have been cheaper than replacing the entire assembly. In the not-too-distant future, this ability to make parts on demand will become a viable option. And the car companies might actually make more money on it.

To recap, intelligence will not just be part of the advanced manufacturing platform but will become imbedded into the parts, components, assemblies, and systems it produces. This creates an entire ecosystem tied together through robust digitalization, communication, status checks, and work flow. Intelligence indeed.