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# **AC 2011-1858: RESPONDING TO EMERGENCIES USING LOCAL INDUSTRY: SERVICE LEARNING WITH MANUFACTURING ENGINEERS**

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## **Responding to Emergencies Using Local Industry: Service Learning with Manufacturing Engineers**

“A cool glass of water is worth little under normal circumstances, but if the circumstance is great enough, a cool glass of water can be worth considerably more”<sup>15</sup>

### Introduction

The concept of “just-in-time” has had a variety of applications, most notably in manufacturing industries, where the practice of producing items only as needed has enabled a large reduction in levels of inventories, reduced space required for production, and other cost and quality benefits. The approach was developed most fully at Toyota<sup>1,2</sup> as a key feature of the Toyota Production System. Retail industries<sup>3,9</sup> have used just-in-time as a means to reduce stock and inventory levels resulting from improved forecasting technology, a shift to centralized warehousing, and the use of faster, more frequent, and more reliable transportation methods. The advent of e-commerce has allowed participants in supply chains to remain in close communication about demand and supply, further enabling just-in-time. Unfortunately, the shrinking inventory levels that help reduce costs for suppliers of goods end up being bad for local providers of emergency services. These providers, who respond to major events such as earthquakes, floods, wildfires, or terrorist attacks, often depend on a reliable local supply of goods that can be distributed as needed in such circumstances. Smaller inventory in local warehouses means more difficulty in responding to emergencies. Instead, these agencies have been forced to resort to other high-cost alternatives, such as stocking critical items themselves or planning for rapid import of needed goods from some other region. Recent events such as the Katrina flooding in New Orleans and the earthquake relief efforts in Haiti have underscored the importance of local regions becoming self-sufficient (at least for a few days) and have highlighted the incredible costs of flying in large quantities of goods (e.g., bottled water) to a hard-hit region.

Most communities, however, do have considerable local manufacturing capacity. Although the trend of shifting production overseas has diminished the base of producers in the United States, there is still tremendous capacity and most cities have a number of fabricators of metals, plastics, or other goods. In theory, that manufacturing capacity could be used to produce items that are needed by local residents in the event of an emergency but that are no longer available in locally stocked warehouses. General purpose goods such as water containers, water filters, repair or reinforcement materials, first aid supplies, tent or temporary living supplies, toilet or other sanitation items, or blankets and clothing could be produced as needed in many communities by the local manufacturing base. Even more complex items, such as power generators, water treatment stations, or medical care items could be assembled and provided from the capacity in most sizable communities of local manufacturers and a reasonably coordinated regional supply chain. These manufacturers, however, are generally not ready to drop what they are doing at any one time and rapidly start producing the needed items. They do not have the tooling, the methods, and the plans for coordinating materials and efforts to accomplish it. They also currently have no financial or other incentive to be so prepared. Nevertheless, over the course of many years touring the manufacturing operations of regional companies, it has become clear at least to this author, that an immense manufacturing capacity exists as a whole throughout the many industrialized areas of the country.

In order to match the capacity of local manufacturers with the need for a ready supply of certain goods in the event of an emergency, some financial incentive or leveraged assistance must be provided to the companies. The incentive and the assistance can both come from university students and teachers as a form of service learning. Service learning<sup>4,5</sup> is a growing trend in universities in which students participate on an educational project that applies their knowledge while contributing meaningfully to their communities. Service learning engages students by giving their work significant purpose and reinforces their commitment to their discipline by seeing it directly benefit humanity. This contribution to community welfare, even more so than contributing to a company's bottom line of profits, motivates modern students and gives them emotional investment in their chosen field. Since few fields have struggled with student recruitment and retention (especially of females and other underrepresented groups) in the past decade as much as manufacturing programs and engineering programs, it seems an extraordinary match of interests to have students that study manufacturing and engineering participate in service learning projects that provide assistance to local manufacturers to encourage them to be ready to rapidly supply needed goods in the event of an emergency.

There is much that students could do to facilitate the rapid local manufacture of needed emergency goods. In order to rapidly produce goods that are not otherwise the company's normal products, the organization needs tooling, methods, training, and a plan to coordinate materials and efforts. Student groups can design and build tooling such as fixtures or molds that would enable quick set-up and simple processing of components. Student groups can plan the methods and procedures of that processing to minimize lead time and simplify the efforts of available personnel. Student groups can help company's analyze their supply chains to identify potential paths for rapid supply of needed materials. Student groups can plan logistics and distribution of goods in coordination with local emergency services. All of these efforts would be excellent educational opportunities for students and would provide the emotional motivation of direct service learning.

Even if no emergency comes about, most companies would still benefit from the focus on short set-up times, flexible production, and rapid response that these efforts would involve. The trends towards flexible manufacturing<sup>13,14,16</sup> are well-known over the last two decades. The ability of a company to react to changing product designs, changing quality requirements, changing order schedules, and changing physical, legal, or political environments is its flexibility. Reduced lead times due to this flexibility are increasingly what sets companies apart and what enables some companies to grow market share while others falter<sup>6,12</sup>. As global competition increases, nearly every industry in the US has been pushed towards more flexible production. Although it is therefore in most company's best interest to become more flexible, it does take some investment. Working with universities and such service learning projects as describe above is an excellent way to reap the advantages of improved flexibility while minimizing investment.

### Service Learning in Preparation for Emergencies

Efforts have begun at one university to accomplish just such a transformation using service learning as a tool for both recruiting and educating new engineering students around projects dealing with the rapid production of goods in the event of a local emergency. The intent is to simultaneously benefit the students, the community, and the local manufacturing base. The

projects that make up the effort are coordinated as the RELI Center, for Responding to Emergencies using Local Industry. The name of the effort also derives from the belief that if communities would come to rely more on local manufacturing, there would be more pressure to keep the manufacturing base intact rather than shift that capacity overseas. A closer interdependence between the manufacturing base and their local communities can and should strengthen both. The objectives of the project are as follows:

- Identify local emergency needs from which to form a framework of collaboration;
- Establish a relationship with local industry and convince them to try some projects on a pilot basis;
- Launch a series of related projects with the university students based on classroom, project, or student club activities; and
- Learn from the projects, redefine new efforts, and publicize project successes.

To accomplish these, the students and faculty involved contact the local Emergency services offices for information. This may include city, county, state, or federal offices, as well as relief agencies such as Red Cross. Face-to-face interviews and research into disaster records and regional history can provide a good guide to the most likely emergency scenarios. Expert opinion and research into emergency/survival products catalogs can also give a good idea about the types of items likely to be needed. A survey of local or regional industry and their capabilities is required to get a sense of what is possible and who might be likely participants. Since services, such as electric power, may be out in a given location, it is often important to consider “sister” communities or adjacent regions that might be capable of providing goods to a nearby emergency.

The projects involved can vary widely in scope but should focus on items that are likely to engage students and encourage industry/agency participation. Engineering programs typically have many avenues for working on design projects, be they class/lab assignments, capstone projects, or student club or extracurricular activities. It is certainly possible that projects may be funded by the industry partners involved, but due to the pilot nature of such an effort, it may be wiser to start the effort as purely a “service learning” activity, in the true spirit of community service. The products to be developed can be original designs, modified versions of existing products, or even existing products that are not currently planned for rapid production and distribution.

Publishing the efforts of the projects is an important component of establishing the link of interdependence between community, school, and industry. Technical and trade publications can both be used to grow an understanding of common community goals. Local publications or events can help to spread the word and build a sense of mutual reliance.

#### Local and Regional Preparations for Emergency

Much was learned from a series of interviews with officers of the local County Office of Emergency Services<sup>7</sup>, Fire Department<sup>8</sup>, and with volunteer coordinators of the local American Red Cross<sup>10</sup> affiliate and local VOAD (Voluntary Organizations Active in a Disaster) group<sup>11</sup>.

The knowledge gained from these interviews was sobering in some sense but very helpful for the projects. It was determined what emergency or disaster scenarios are the most likely and what are current plans to respond. The officials described the items in most need under various scenarios, including those that are typically available in local storage and those that are not. They described the likely effects on public services such as power, water, and phone infrastructure and the level of backup systems prepared. They also discussed the communications systems in an emergency and the general “competition” for resources among the responders in a crisis.

Major wildfires and earthquakes were found to be the most likely wide-scale emergencies in the local area. Although wildfires are more likely there is also generally more advance warning associated with them. Terrorist activity, especially targeted at a nuclear power plant was also a significant concern. Current response plans to these events are very well considered – for small-scale relief. Concrete, realistic plans were described for response to an emergency affecting a “neighborhood” or concentrated resident dwelling (e.g., dorms, assisted living homes, etc), but it was admitted that a response to a truly widespread regional event (i.e., on the order of Katrina or Haiti) would be much more uncertain and would likely have many more “gaps” in coverage.

The items most in need in the event of an emergency depend of course on the nature of the emergency but many common needs exist. Reliable access to clean water (for drinking and sanitation) was mentioned the most across the scenarios. Therefore, products for treating, filtering, storing, or distributing water are of great concern. Items related to temporary home shelters were also considered critical: tents, beds, toilets, blankets, heating/cooking products, etc. Food and medical items, cleaning supplies, and structural/reinforcing tools and supplies were listed as crucial as well. Also described for nearly any disaster scenario were “quality of life” items that essentially keep people sane and well-behaved during extended periods of isolation, despair, or confusion – including lights, heat, radio/tv, internet, and phone access. A few of these items (e.g., structural/reinforcing supplies) would likely be available locally in sufficient amount at hardware or other stores if needed. While an excellent backup system exists for phone service (in place largely for mobile communications between responders themselves), much less reliable is the backup plans for water and electricity. It was thought that residents should be prepared to be without these for “several days” in the event of a wide-scale emergency. Water, and the competition for it, was described as a particular concern because even if the event does not start from wildfires, the chances of spreading fires (e.g., from an earthquake) are quite large, and services such as the fire department will make a claim for much of the available local water storage.

### Design Projects (2007-2011)

Several projects have been undertaken at the author’s university since 2007. The projects have varied in scope, approach, and results, but at least one successful model appears to be emerging.

The first project involved a student club preparing to enter a regional engineering design competition. The project was the design of a working bicycle-powered electric generator (the E-Spin). An electric generator would be useful in many emergencies, especially a large earthquake in which most public services are compromised. The generator was designed for use by a single

family or small neighborhood and so production on the order of hundreds would be appropriate for a modestly-sized city (one of the common elements of wisdom from the public emergency services sector was that large cities would likely drain all of the federal relief efforts leaving many smaller communities at the most risk). The design was essentially original and developed from the components on up. The product itself is really just a stand for a bicycle that is attached to an alternator, a battery, and a power inverter (Figures 1 and 2) for standard AC or DC output, with voltage and current dependent on alternator and pedaling speed (6-12 Volts, 1-4 Amps). The design is meant to allow virtually any standard bicycle to be quickly hooked up to the stand (Figure 2). A few minutes of pedaling can produce enough electricity to allow for lighting, charging of a phone, playing of a radio, or other low current, “quality of life” activities. The intention was more to charge the battery for these purposes rather than having someone constantly pedaling while the load is operational.

Rather than work with a specific company that would produce and assemble the items themselves, the design team took the approach of “designing for Home Depot®” and the idea that almost any generalized machine shop could produce the items with minimal preparation and set-up. They only specified parts that could be readily found at local hardware stores and that would likely be in plentiful supply at any given time in most communities. The process design includes a set of drawings and instructions for cutting, welding, light machining, and assembly. The fabrication steps are to be performed at local manufacturers (using common welding and machining tools) and require just two small dedicated fixtures for quickly locating and drilling holes. Any shop willing to produce the products would need to make the fixtures ahead of time and have a basic plan for acquiring the components. The manufacturers then produce the components and complete the basic assembly using easy-to-follow mechanical fastening instructions created by the student group. Once distributed to the public, the E-spin can be easily adjusted by the user to fit virtually any bicycle within minutes.

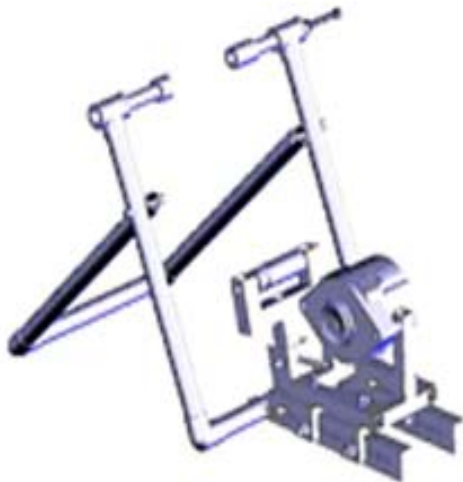


Figure 1 E-Spin Generator Design

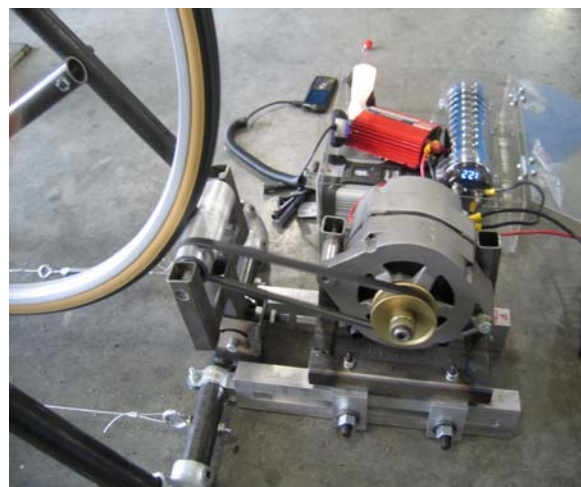


Figure 2 Assembled Generator

The results of this initial project were very positive but not without some logistical concerns. The students successfully designed and fabricated a working prototype (see Figures 3, 4, and 5).

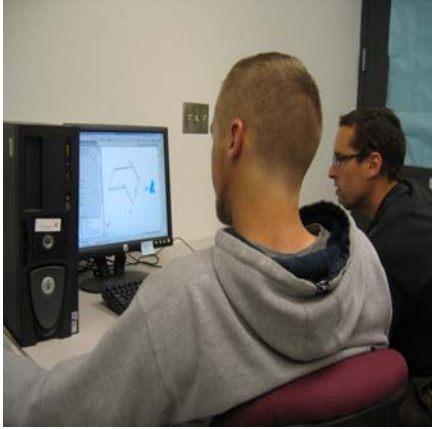


Figure 3 Team Design



Figure 4 Team Assembly



Figure 5 E-Spin in Action

The prototype was able to power simple household electronics and charge a battery but it did require a fair amount of heavy pedaling, even for well-conditioned college students. It became clear that a new design generation was needed to more efficiently harness the pedaling power to make the product more user-friendly. The design also ended up quite heavy and with over 200 components (over 70 separate parts of varying quantities), which is simply too many for quick and efficient manufacture. Although the vast majority of the components are easily obtained (e.g., screws, nuts, washers, cables, tubing), a few require a bit more searching (alternator, battery, inverter). Due to the needs for redesign, the project was not ultimately taken to local manufacturers to establish an arrangement for eventual production and distribution. It was determined, however, that the product (or a redesign) could serve as a more traditional emergency item that is produced and sold for storage in the home ahead of an actual emergency. In fact, the ability to neatly fold up and store the device was designed into the product for the final version.

The second project was an extension of the first and focused on a redesign of the bike generator using DFA principles for simpler and quicker assembly by local manufacturer. This project was undertaken by a single student as a capstone senior project experience. The student examined the product materials, the production methods, and the product functionality and was able to make a number of improvements. The changes were based on research into Design for Manufacture (DFM) and Design for Assembly (DFA) guidelines and human factors considerations. A new working prototype (Figure 6) for the bicycle generator was eventually designed and constructed. Its main improvements consist of:

- A significantly lighter assembly: By replacing the original steel frame with one made of aluminum, the weight was reduced by more than 50%. The new design can be easily moved and setup by a single person
- A shorter, simpler production process: By simplifying the base on which the alternator is mounted (Figure 7), the number of weld areas is reduced from 10 to 4. By utilizing bent pipes, rather than mechanically joined straight pipes and fittings, the number of frame parts was reduced from 10 to 2. By these changes and replacing the pulley system with a direct-drive friction knob on the alternator, the # of separate parts overall reduced from 70 to 30. The shop, however, is required to have a pipe bender on hand.



Figure 6 Revised Bicycle Generator Design

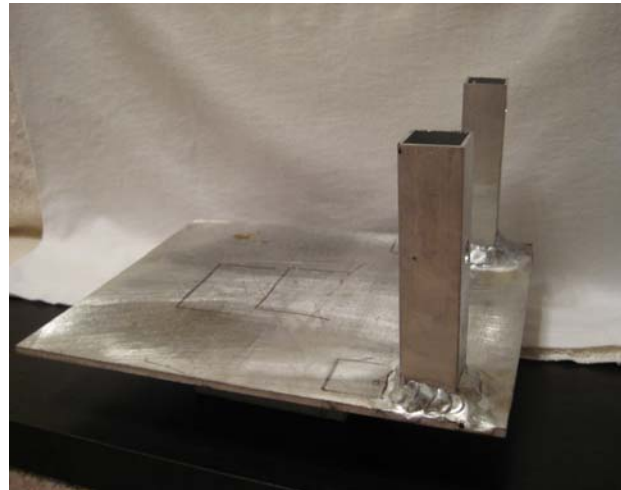


Figure 7 Simplified Alternator Base

- A reasonable estimate of fabrication and assembly time: A single complete unit of the revised design can be fabricated in approximately 4½ hours, including 1 hour of setup, 3 hours of component fabrication, and an average tested assembly time of 20 minutes. For multiple units, the total time would depend on how many machines and operators could be dedicated to the project.

A third project was launched from the RELI effort but really ended up going in a different direction. The idea was to refocus the lab activities in the freshman-level machining course taken by most engineering students. Historically, the lab involves the physical production of small air-driven motors, consisting of 12 component parts that get machined and assembled in a simulated factory setting. The motors convert the energy in compressed air to the kinetic energy and momentum in a rotating flywheel. Other than that, the motors serve no real function other than as a keepsake. Two senior students developed a design for a water pump that could be machined in the freshman lab instead. However, the pump that was eventually decided on was more suited to pumping water from a well than for use in emergency situations. Ultimately, the students decided to design the pump as something that could be donated to humanitarian organizations that would distribute them as needed in developing regions throughout the world. The design was finalized and a prototype pump produced. Several fixtures were also designed and fabricated for use in the freshman lab class. The transition of the regular lab activity itself away from the air-driven motor is an ongoing activity being worked on by the course instructors.

The final and current project being attempted is more in line with the goals of the RELI center. Overall, the objective is to design a product along with a production and distribution plan for wide-scale water treatment and filtration. The design objective for the system is for it to be able to provide at least two liters of potable water per day for up to 10,000 people, and for it to be operable and in place within 48 hours of an emergency. A team of two graduate students designed a new product in collaboration with a local manufacturer that produces water purification systems. The new product is capable of treating 750 to 1,500 liters of water per hour, and several units would need to be produced and stationed near suitable water sources.



The product itself is a fully integrated, ozone-based system for purifying water for human consumption. The design is a variant of certain existing systems already produced by the manufacturer. It includes a skid-mounted assembly (Figure 8) of six subsystems: a pump for drawing surface water with a positive pressure head; a pre-treatment filter for filtering out particulate and mineral contaminants from the source water; an electric-arc corona discharge (CD) ozone ( $O_3$ ) generator; an injection manifold where the ozone is mixed into the incoming water; a large fiberglass contact tank in which water sits while the ozone is reacting with contaminants; and an activated carbon post-filter to remove taste-degrading chemicals. The new design was created to be used with local water resources (lakes, swimming pools, reservoirs, etc.) that are expected to be available during an emergency, whereas most of the existing products are designed for just pools and hot tubs. Gas-powered electric generators will also be needed at the treatment site to ensure a reliable source of electricity for the systems. The design also considers the need for rapid production and distribution which is rarely needed in the normal products the company makes.



Figure 8: Skid-Mounted Ozone Generator

Two phases of the current project have been completed so far. The first phase dealt with analyzing the number of local water sources and the system's capacity for water treatment to determine how many skid-mounted systems would be needed and where they would need to be placed in order to achieve project goals. Under differing scenarios (including varying daily demand and varying system flow rate), a computer simulation model was created and run to find that between 2 and 4 systems would be sufficient to meet water demand with high confidence. Large local pools, reservoirs, storage tanks, and one lake were identified as potentially suitable water sources.

The second phase of the project dealt with an analysis of the manufacturing process at the participating company. The activities included observing and videotaping the assembly process for a similar product. The students then formally documented the assembly process for the new product and identified the bottleneck areas to be studied for reducing overall production lead time. The original estimate for one person to assemble a system is 20 hours (with very little pressure to reduce it), but a review of the process in place has suggested that many opportunities exist for reducing that time for production in the event of an emergency. A set of product design recommendations has been made to reduce the number of fasteners and other components in the assembly to reduce the setup and assembly time. Further recommendations were made to simplify the assembly process itself by using various fixtures and by reallocating the tasks of assembly personnel. Some the changes would reduce the aesthetic value of the system but would greatly streamline the production process. Other changes would take advantage of the ability of more than one person to work on the assembly (i.e., tasks done in parallel), which does not

normally take place. The company has been very interested in the idea of drastically reducing its lead time, not just for emergency production but for going after different market segments with their products.

### Lessons Learned and Ongoing Efforts

Although the RELI effort has been ongoing for about three years as of this writing, it still seems to be in its infancy. Several lessons have been learned so far that will hopefully inform future projects. Most importantly, it has been difficult to maintain continuity across student projects as the students themselves come and go fairly regularly, and students have a natural reluctance to select a project to work on that has already been attempted. The projects that have been started really require several generations of students or iterations of design effort, and sincere efforts must be made to keep a steady stream of students working on the projects. Various incentive measures, such as project funding, will be used in the future to keep the projects progressing without any gaps. It has also been challenging to keep industry partners involved, although a consistent focus on the benefits of the project to the industry partner has helped. Communications with local emergency personnel have been much more difficult than originally estimated, mostly because the emergency services offices are generally understaffed and the workers frequently dispatched to other locations to attend to various emergency events. Lastly, the school has learned to be open in terms of which directions these projects end up. There are many ways of helping a community, and many communities that need helping, both local and global. The projects have not always ended up moving in the direction that was initially anticipated, but the students involved have all had extremely satisfying experiences and have been strongly motivated to succeed.

### Conclusions

A new educational approach is presented that intends to integrate the goals of engineering education with broader goals of community service and vibrant manufacturing infrastructure. The RELI Center has launched several student projects that have a unifying goal of helping to prepare the local community to weather a wide-scale emergency. The efforts have tried to engage local manufacturers to be prepared to produce needed items for the community in the event of an emergency. Local emergency services offices have been brought into the arrangement and have provided input on the nature of likely emergencies and the types of products that would be of greatest benefit. The student projects have involved the design of new products and systems and the design of the corresponding processes of manufacture. The designs have placed emphasis on a production environment focused on rapidly setting up and producing the parts in anticipation of an unplanned emergency need. Industry partners have agreed to participate, partly because of the benefits of developing flexible, rapid-response capability. The students have all had rewarding experiences and have learned about manufacturing issues as well as emergency relief efforts. Although no solid systems have been put in place to actually initiate production of goods in the event of an emergency, efforts are ongoing and steady progress has been made towards that goal.

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