Project Number: 49-HXA-9921

The Transfer of Technology to Small and Medium Sized Manufacturers

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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Date: May 4, 2000

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1. **technology transfer**
2. **CNC**
3. **machining**

Professor Paul Cotnoir, Co-Advisor

LETTER OF TRANSMITTAL

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May 04, 2000

Dear Professor Ault and Professor Cotnoir,

Attached is one copy of the Interactive Qualifying Project: **The Transfer of Technology to Small and Medium Sized Manufacturers**, Project Number 49-HXA-9921

Sincerely,

_____

Mitchell W. Olszta

_____

Karl Klemm

Distribution: Library: 1 Copy
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PREFACE

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed within the report are those of the authors, and they do not reflect the opinions of the Massachusetts Extension Partnership, National Institute of Standards and Technology, or Worcester Polytechnic Institute.

This report is the result of an educational program, and is to serve as partial documentation of the evaluation of academic achievement.

ACKNOWLEDGEMENTS

We would like to take this opportunity to thank all the individuals and organizations that have contributed to this report. Professor Ault has guided us in completing this Interactive Qualifying Project. Her expertise, patience, and constructive criticism have greatly contributed to the success of this report. Professor Cotnoir directed us into the conception of this IQP and monitored our weekly progress. He has taken time away from his daily work schedule to help us in the construction and overcoming the obstacles faced throughout the project. We would also like to thank Matt Shaver and Fred Proctor for their expert knowledge on the Enhanced Machine Controller.

The Massachusetts Manufacturing Partnership has enabled the use of a computer and various other resources for the IQP. The National Institute of Standards and Technology permitted visits to their Gaithersburg, MD site, and documentation of the progress EMC has gone through.

ABSTRACT

This project's goals were to give the Massachusetts Manufacturing Extension Partnership in cooperation with the National Institute of Standards and Technology a report that documents and assesses Enhanced Machine Controller technology (EMC). The project involved the surveying of current users and a market analysis to determine the feasibility of transferring the EMC technology from a federal laboratory to a small manufacturing enterprise. This study shows that EMC is a great asset to industry, but it is still in a developmental stage and is not yet suitable for transfer to small manufacturers.

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AUTHORSHIP

1.0 INTRODUCTION

Technology plays a very important role in industry. To get the technology from the laboratory to industry it must somehow be transferred. There are several methods used in technology transfer, these methods are discussed in detail later. Technology transfer is a very valuable tool used to stimulate and further industry.

The National Institute of Standards and Technology (NIST), a federal laboratory, and the Manufacturing Extension Partnership (MEP), an organization which helps small manufacturers improve themselves, are looking for the best way to transfer Enhanced Machine Controller (EMC) technology to small and medium sized enterprises (SME). EMC is an open architecture software package that was developed to provide small manufacturers with a low cost alternative to expensive machine controllers, which would improve the SME's productivity.

This Interactive Qualifying Project (IQP) looks at the different methods of technology transfer, and the specific case of transferring EMC technology to SMEs. In addition, a study on how EMC technology affects industry and the viability of marketing EMC was done. Research was done on how to make the transfer of EMC technology easier and more efficient.

1.1 TECHNOLOGY TRANSFER OVERVIEW

Technology transfer is vital to the rapidly growing high tech industry. The research and development of new technology requires a medium for its distribution. The avenues that have developed for transfer of new technologies are primarily for private industries. The private industries need these avenues of communication for the coordination of technology transfer with federal laboratories.

Technology transfer is a win-win situation for both the private sector and the federal laboratories that create new technology. The means by which the technology is transferred if it has the ability to be transferred, is up to the organization coordinating with the private sector. That is exactly what MEP must do with the new EMC technology.

1.2 CNC OVERVIEW

In 1952, the term numerical control was coined. CNC is a program allows the motion of a machine tool to be controlled by a computer rather than by a machinist. The purpose of CNC capability is to machine more complex parts faster with accuracy. Many machines in the metal working industry are now equipped with CNC. Without CNC, the design and turnaround times of parts are greatly increased (Chang, 1998).

1.3 RETROFIT OVERVIEW

A Retrofit is the overhauling of an older machine to update its components. A retrofit can entail two options, 1) adding Computer Numerical Control (CNC) capability to an existing manual machine, or 2) upgrading the motors and the machine controller/software. The EMC technology replaces the machine controller and software as a machine retrofit.

1.4 EMC OVERVIEW

EMC is an open architecture computer program that NIST develops and runs under Real Time Linux, a derivative of Linux. EMC takes the place of a normal machine controller. It features open architecture, meaning the user can alter the software anyway he or she sees fit. A PC with EMC and RTLinux on it can control virtually any machine

regardless of make, model, or motor type. EMC technology provides CNC capabilities at a fraction of the cost compared to its competitors.

1.5 THE NEED FOR EMC

In 1980, the United States manufactured nearly half of the machine tools in the world. Today, our market share is 10%. Because machine tool technology is critical for both civilian and military uses, it is important to maintain and possibly recapture some of this market (Proctor 1999).

In order to remain competitive, machine tool manufacturers must develop and maintain advanced technology. The industry is fragmented and composed mostly of small specialty manufacturers without great financial resources. Therefore, their ability to develop and implement advanced technology is very limited. Open architecture controls will reduce development cost because off-the-shelf components will be available from multiple sources, and less engineering time will be required to integrate these components into systems (Proctor 1999).

Open architecture systems allow sensors to be added to enhance capabilities, third party software can be integrated by users, and programming language dialect can be supported without system redesign. Finally, training and maintenance costs will be reduced by standardization (Proctor 1999).

1.6 PROBLEM STATEMENT

"There is nothing small about small manufacturers." Those were the words spoken by U.S. Department of Commerce Secretary William M. Daley, as he declared 1999 as the Year of the Small Manufacturer. The age of the small business is upon us,

and in order to prosper and remain competitive the small business must adapt to new technologies. Small manufacturers with fewer than 500 employees make up 98% of all U.S. manufacturers and they provide for 65% of all manufacturing employment. That is, 1 in every 10 Americans is employed by a small manufacturer, and this makes up a total of 12.2 million jobs. Large manufacturers are systematically downsizing, and consequently depend on the 385,000 SMEs in the United States for specialized activities.

Although the SME is a critical entity to the U.S. economy, they are less likely to get the knowledge of new technology that will benefit them than larger manufacturers. The small business falls behind in technology advancement due to significant barriers (MassMEP, 1999). These barriers include:

- Shortage in technical staff
    - Fear of technology
    - Can't provide ongoing support for new technology
    - Unsophisticated
- Isolated from outside world
    - Don't learn about new ideas
    - May be rural
    - Generally don't use consultants
- Financial constraints
    - Quick payback required
    - Can't afford R&D

The MassMEP in conjunction with NIST has been tackling those problems since 1989. The breakthrough is not easy though, and transferring the technology can be cumbersome. We are tasked to research and study the methods of transferring technology from federal labs to SMEs. The research will investigate the ways in which technology transfer has been best utilized in the past. This project will also derive, and implement an effective method to facilitate the transfer of a computer numerical program known as EMC (Enhanced Machine Controller) from the NIST (National Institute of Standards and Technology) to small businesses. MEP would like to use a modular and portable demonstration site for transferring the EMC technology.

2.0 LITERATURE REVIEW

The following literature review provides information about technology transfer. In addition, information on, CNC, retrofitting, and EMC has been included. This information is vital to understand the use of EMC as a case study for the transfer of technology from federal laboratories to SMEs. The information in this section has been provided through the Massachusetts Manufacturing Extension Partnership and National Institute of Standards and Technology. A large amount of data has been gathered on EMC and its conception by traveling to Washington D.C. and meeting with Fred Proctor, the developer of EMC. Matt Shaver, an original tester of the EMC program, has also been consulted for information regarding EMC. Other data for the literature review came from technology handouts, books, and available web sites that provide information about technology transfer.

2.1 NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

The National Institute of Standards and Technology is an agency of the U.S. Department of Commerce's Technology Administration. Established in 1901, NIST strengthens the U.S. economy and improves the quality of life by working with industry to develop and apply technology, measurements, and standards. It carries out this mission through a portfolio of four major programs: Measurements and Standards Laboratories, Advanced Technology Program, Manufacturing Extension Partnership, and Baldrige National Quality Award. NIST operates primarily in two locations Gaithersburg, MD and Boulder, CO (National, 1999).

Currently, NIST is working in cooperation with the Manufacturing Extension Partnership (MEP) to provide a low-cost means of transferring NIST control technology,

while providing a flexible software base on which future enhancements can be delivered. Several small job shops across the country have already been selected for beta installations.

2.2 MASSACHUSETTS MANUFACTURING EXTENSION PARTNERSHIP

MEP's primary mission is to give hands on technical assistance to SME manufacturers trying to improve their operations using appropriate technology. Unfortunately, in a telephone interview of 200 SMEs, 163 of those 200 had not previously heard of the MEP. That is 82% of the pool were unaware of MEP's services (Cotnoir, 1999).

The Massachusetts MEP is part of a nationwide network of more than 70 not-for-profit centers whose purpose is to provide SMEs with the help and solutions they need to succeed. There are MEP centers in all 50 states, linked together through the Department of Commerce's National Institute of Standards and Technology. This makes it possible for even the smallest firms in Massachusetts to have access to more than 2,000 manufacturing and business specialists - including the staff of the Massachusetts MEP and their specialized knowledge about doing business in Massachusetts (Massachusetts MEP, 1999).

2.3 TECHNOLOGY TRANSFER

The legislature, methods, organizations that deal with technology transfer, and research and development will be discussed in detail. The legislature enables the SMEs to benefit from new technologies developed through federal laboratories.

2.3.1 LEGISLATURE

Beginning in the early 1980's the United States government established Legislative Act's that promote the transfer of technology into SMEs. A comprehensive list of those acts is given below: (Technology Transfer Legislative History, 1999)

"Bayh-Dole Act of 1980 (PL 96-517)

- Permitted universities, not-for-profits, and small businesses to obtain title to inventions developed with governmental support.
- Provided early on intellectual property rights protection of invention descriptions from public dissemination and FOIA.
- Allowed government-owned, government-operated (GOGO) laboratories to grant exclusive licenses to patents.

Small Business Innovation Development Act of 1982 (PL 97-219)

- Required agencies to provide special funds for small business R&D connected to the agencies' missions.
- Established the Small Business Innovation Research Program (SBIR)

Federal Technology Transfer Act of 1986 (PL 99-502)

- Made technology transfer a responsibility of all federal laboratory scientists and engineers.
- Mandated that technology transfer responsibility be considered in employee performance evaluations.
- Established principle of royalty sharing for federal inventors (15% minimum) and set up a reward system for other innovators.
- Legislated a charter for Federal Laboratory Consortium for Technology Transfer and provided a funding mechanism for that organization to carry out its work.
- Provided specific requirements, incentives and authorities for the Federal Laboratories.
- Empowered each agency to give the director of GOGO laboratories authority to enter into cooperative R&D agreements and negotiate licensing agreements with streamlined headquarters review.

- Allowed laboratories to make advance agreements with large and small companies on title and license to inventions resulting from Cooperative R&D Agreements (CRDAs) with government laboratories.
- Allowed Directors of GOGO laboratories to negotiate licensing agreements for inventions made at their laboratories.
- Provided for exchanging GOGO laboratory personnel, services, and equipment with their research partners.
- Made it possible to grant and waive rights to GOGO laboratory inventions and intellectual property.
- Allowed current and former federal employees to participate in commercial development, to the extent there is no conflict of interest.

Executive Orders 12591 and 12618 (1987): Facilitating Access to Science and Technology

- Promoted the commercialization of science and technology.

Omnibus Trade and Competitiveness Act of 1988 (PL 100-418)

- Placed emphasis on the need for public/private cooperation on assuring full use of results and resources.
- Established centers for transferring manufacturing technology.
- Established Industrial Extension Services within states and an information clearinghouse on successful state and local technology programs.
- Changed the name of the National Bureau of Standards to the National Institute of Standards and Technology and broadened its technology transfer role.
- Extended royalty payment requirements to non-government employees of federal laboratories.
- Authorized Training Technology Transfer centers administered by the Department of Education.

National Institute of Standards and Technology Authorization Act for FY 1989 (PL 100-519)

- Established a Technology Administration within the Department of Commerce.
- Permitted contractual consideration for rights to intellectual property other than patents in cooperative research and development agreements.
- Included software development contributors eligible for awards.
- Clarified the rights of guest worker inventors regarding royalties.

National Competitiveness Technology Transfer Act of 1989 (PL 101-189)
(Included as Section 3131 et seq. of DoD Authorization Act for Fy 1990)

- Granted GOCO federal laboratories opportunities to enter into CRDAs and other activities with universities and private industry, under essentially the same ways as highlighted under the Federal Technology Transfer Act of 1986.

- Allowed information and innovations, brought into, and created through cooperative agreements to be protected from disclosure.

- Provided a technology transfer mission for the nuclear weapons laboratories.

Defense Authorization Act for FY1991 (PL 101-510)

- Established model programs for national defense laboratories to demonstrate successful relationships between federal government, state and local governments, and small businesses.

- Provided for a federal laboratory to enter into a contract or memorandum of understanding with a partnership intermediary to perform services related to cooperative or joint activities with small businesses.

- Provided for development and implementation of a National Defense Manufacturing Technology Plan.

Small Business Technology Transfer (STTR) Program 1992 (PL 102-564)

- Established a 3-year pilot program - Small Business Technology Transfer (STTR), at DoD, DoE, HHS, NASA, and NSF.

- Directed the Small Business Administration (SBA) to oversee and coordinate the implementation of the STTR Program.

- Designed the STTR similar to the Small Business Innovation Research SBIR program.

- Required each of the five agencies to fund cooperative R&D projects involving a small company and a researcher at a university, federally-funded research and development center, or nonprofit research center."

2.3.2 METHODS AND EXAMPLES

When the subject of technology transfer is mentioned the main thought that comes up is there are so many ways to get technology from the laboratory to the real world. However, upon examining the subject closer and doing research, one can conclude that there are very few methods actually implemented.

The most commonly used method that seems to appear repeatedly is that an organization, usually within a network of such, is hired by a business to improve the productivity of the business. The organization then will contact companies and the government to find out if there is technology that could help the business and get that technology to the business (Mechanisms of Tech Transfer, 1999).

Another method that is used along with the previous method is, if no such technology currently exists for the problem, the organization may contact a research and development center to develop the needed technology. The organization would then transfer that to the client business. This second method is less geared towards the transfer of technology but rather more towards the creation of technology (Mechanisms of Tech Transfer, 1999).

A third method of technology transfer is a medium that allows the free exchange of ideas and information between peers. This usually takes the form of conferences, forums, and technology talks (Massachusetts Innovation Economy, 1999). Another way this method is implemented is through publications in newsletters and magazines (Mechanisms of Tech Transfer, 1999), and also mailing lists and chat forums on the Internet (TTNWeb Forums, 1999).

Other technology transfer methods have the same basic idea behind them, but offer a different, and perhaps more specialized perspective. These methods include having a representative from a laboratory go to the client business and determine what the hindrance is and what the best solution is to fix the problem. This allows the workers to be in direct contact with the laboratory personnel. This means that the workers can give the laboratory personnel feedback and help them customize the solution. Other methods

use the same format but also include such things as product licensing and small business involvement in government programs (Mechanisms of Tech Transfer, 1999).

2.3.3 Research and Development

The development of new technology is vital to technology transfer. If no new technology were developed, businesses would fail. One way that new technology is quickly developed is information sharing. This can be achieved by email, phone conversations, publications, etc. However, one of the best methods available is the idea of a joint technology center. This is mainly achieved by combining the resources of a university, or universities, and some larger organization such as a company or government agency (Battlelle Solutions Update, 1996).

Universities are used widely in the development, and occasionally the transfer, of technology. Universities most often have better resources than small businesses in industry. They have many laboratories, a vast amount of knowledge in the form of professors, and much information on different aspects of technology, both in literature and in connection with other universities. As stated before, universities often have connections with other organizations and companies that allow the transfer of technology even more readily than other organizations such as MEP (DOE Pulse33, 1999).

The government plays a large part in technology transfer. NASA, the Navy, and state governments contribute huge amounts of technology to the world, and usually at no cost. The United States is broken up into six regions, each of which has its own technology transfer center. The first of these is the National Technology Transfer Center (NTTC). "NTTC is the hub of a national network established by Congress to link U.S.

companies with federal laboratories to turn government research results into practical, commercially-relevant technology" (NTTC & Mid-Atlantic RTTC, 1999). The others include the Far-West, the Mid-Continent (MCTTC), the Mid-West's Great Lakes Industrial Technology Center, (GLITeC), the Southeast's Southern Technology Applications Center (STAC), and the Northeast's Center for Technology Commercialization (CTC). All of these organizations use the previously stated methods of technology transfer as their tools in assisting industry (uscomp, 1999).

There are several networks of organizations that are involved in technology transfer. They deal with many different divisions of industry and many different problems that these companies have. One of branches of the networks is Mass MEP, which is the Massachusetts Manufacturing Partnership. "The Massachusetts MEP is part of a nationwide network of more than 70 not-for-profit centers whose sole purpose is to provide small and medium-sized businesses with the help and solutions they need to succeed". Mass MEP's field staff has worked in the manufacturing environment and knows how to assess a problem. This gives MEP an advantage that allows companies to receive specialized advice. In addition, all of the organizations like Mass MEP are connected through the National Institute of Standards. This gives Mass MEP's staff access to an immense amount of resources from all over the country (What Is Massachusetts MEP?, 1999).

The National Institute of Standards (NIST) plays an extremely important role in the development of technology. One example is their new enhanced machine controller (EMC) program that helps small manufacturers operate all of their machining tools through a PC. The best part about this is that anyone can get this software free of charge,

just like all of their other products. This allows small manufacturers to gain technology that will improve their productivity at low cost (EMC Technology Transfer, 1999).

The method that is being proposed to transfer the EMC technology is somewhat similar to the other methods of technology transfer but incorporates some new ideas also. To make small manufacturers aware of the EMC program a demonstration site will be set up and interested parties can come and see how the technology works. This will hopefully lead to the companies contacting NIST to receive the program, set up their shop using the new technology and become competitive.

2.4 COMPUTER NUMERICAL CONTROL

Shortly after World War II, the need for complex parts increased, and from that need, the first numerically controlled machine was invented. John Parsons has been credited with developing the concept of numerical control in 1947. He invented a jig bore that was controlled by a computer that used a punch card as its code. In 1949, the United States Air Force commissioned The Massachusetts Institute of Technology to develop a prototype, programmable milling machine. In 1952, the term numerical control was coined. This invention would replace the need for an experienced machine operator who would take years of practice to develop the skill. In the modern machine shop, its automation and flexibility resources dictate the measurement of success (Chang, 1998).

2.4.1 CNC IN INDUSTRY

The role of Computer Numerical Control in today's industry can be found in one-man shops to Fortune 500 companies. CNC machines play a vital role in today's demand for quick turnaround times on services. The CNC machine needs only one set up and many operations can be performed on the work piece. If the work piece is produced by the hundreds then the machine has a fixture set up on it, and an operator simply changes the pieces, and pushes the go button.

The typical CNC machine will cost tens of thousands of dollars, and will have a complicated interface that will replace the experienced machinist.

2.4.2 CNC DEFINITION

The Electronic Industries Association (EIA) defines numerical control as "a system in which actions are controlled by the direct insertion of numerical data at some point." CNC is a system that contains an interface, machining center, and an operator. Together they serve as a powerful tool in the machining industry. The key to a numerical machine is its ability to be flexible, which is to machine different parts by just changing the code. A CNC milling machine has the ability to perform two typical jobs. The first is drilling, this is where the computer interface instructs the machine where to move in Cartesian coordinates, and then performs a vertical Z direction move. The drill spins via a spindle and is then moved into the desired location. This action results in the removal of material at a specified rate. Milling is the second operation and consists of the computer interface instructing the machine locations as described above. The difference is that the Z direction has the ability to move at the same time the X and Y directions

move. There are two distinct motions a milling operation can perform: linear interpolation and circular interpolation. The material is removed via an end mill while feeding into the work piece (Green, 1996). Other information about CNC can be found in Appendix G.

2.5 MACHINE RETROFITTING

A CNC retrofit involves taking an older NC machine and adding new updated hardware to it so that it will work more efficiently. Some of the older machine hardware may be out of service or even missing. That is fine since most of the hardware can be upgraded or replaced. The typical retrofit involves the updating of the user interface and sometimes the machine interface. A personal computer (PC) can be used as the user interface and will contain a program that resembles a traditional machine control readout terminal.

The reason that a retrofit is practical is the cost. A new CNC machine will cost around $100,000 or more. A retrofit can cost as little as $1,000 - $2,000. The new controller of the milling machine will be a PC; this feeds pulse and direction commands through the parallel printer port, to the stepper motors, which translate into machine movement. Software costs anywhere from free, as in EMC up to $20,000.

The costs:

1. Ah-ha Design Group Inc.

• BOSS-RETRO CONTROL about $ 3,600

2. Backtrack CNC

   2531 Pick Lane

   Glenview, Illinois 60025 USA

3. Sherline 5400 Mill System (Flashcut control) about $2,600.00

So, what is all this working up to? This will introduce the small manufacturer to the larger scale CNC machines/controllers/software. Some of the software includes: Master cam, Parametric Technologies ProEngineer, Surfware, and many other programs. The larger more complex CNC machines include Bridgeport, ProtoTrack, Analam, Haas, Maho, and others.

2.6 EMC TECHNOLOGY

EMC is a program that was developed by NIST and runs under RTLinux and takes the place of a normal machine controller, such as a Fanuc or BOSS controller. It features open architecture using the C and C++ languages, meaning the users can alter the software anyway they see fit. One example of this is a back plotter that was developed from the EMC source code by an EMC user. A PC with EMC on it can control virtually any machine, outfitted with either stepper motors or servo motors, whether it is a lathe or a mill, 2 axis, 3 axis, even 4 axis. EMC is made up of four components: a motion controller, a discrete I/O controller, a task executor which coordinates the controllers, and an interface, either graphical or text based.

The concept behind EMC is a great one: to provide a low cost alternative for those who can't afford a more expensive one. This will allow SMEs to increase their income, stay competitive with larger manufacturers, and stimulate the economy. The

method that NIST is using to both develop and transfer their EMC technology is very ingenious. By including the end-users in the development, both the software quality and knowledge base for the software are greatly improved. However, since new versions of EMC are produced every month, keeping up with the latest release, and dealing with any new bugs in the software can be quite time consuming.

Fred Proctor is the developer of EMC. Mr. Proctor works for NIST and is the overseer of the EMC project. He has developed the EMC program for the Real Time Control System research group, small manufacturers, and universities collaborating via research associates. The National Institute of Standards and Technology Intelligent Systems Group, has taken on the challenge of developing and monitoring EMC. Mr. Proctor also works on developing the associated modular interface specifications, validating those specifications, and transferring the resultant technology to small manufacturing companies.

Mr. Proctor is using the World Wide Web as a dissemination medium for the EMC technology. This gives the program accessibility to anyone that wishes to use EMC.

2.6.1 EMCMOT

The motion controller can be set up to fit the machine that is being controlled. The user can set the limits, home position, PID servo compensation with zero, first, and second order feedforward, velocity and acceleration, it also allows individual axis jogging, queued blended moves for linear and generalized circular motion, and programmable forward and inverse kinematics.

2.6.2 EMCIO

Discrete I/O controllers are highly machine specific and therefore cannot have a default value. Because of this, EMC uses EMCIO to setup the interface between the PC and the machine without altering any of the core source code. This feature allows the user to have several different EMCIO files for different machines, and therefore can run multiple machines with the same controller.

2.6.3 EMCTASK

The task executor is used to execute G and M code programs, which are fairly portable, meaning the execution of these program's does not vary much between different machines. The task executor links the motion controller and the discrete I/O together and allows their control via the GUI. In a sense, the task controller is EMC's "operating system", it controls and links together all of the different parts of EMC.

2.6.4 LINUX

Linux is an operating system based on the Unix operating system. It was created by Linus Torvalds, with assistance from other programmers the world over. Some of its trademark characteristics include free distribution, open source code, and networking capabilities. These make it an ideal operating system for software developers. Other features that make it popular in industry are true multitasking, virtual memory, computer code libraries, and other Unix-like features. Linux also contains XWindows, which is a graphical operating environment, similar to the MS Windows operating system. One

very powerful tool that can be implemented using Linux is RTLinux, real time Linux, which EMC uses (Linux Online, 1999).

2.6.5 REAL TIME LINUX

We will go into what real time refers to later. RTLinux is an extension of Linux that handles tasks that must be completed in a set amount of time. This is critical because if a time-critical operation is interrupted by another task, a major problem could arise. An example of this would be a PC controlling a robot carrying a load. If some task were to interrupt the control program for the robot, the robot could malfunction and there could be damage (Linux Online, 1999).

3.0 OBJECTIVE

The overall objective of this IQP is to study and determine appropriate methods for the transfer of EMC technology. An understanding of how these methods are used in technology transfers from federal laboratories to SMEs is documented. A market study of the Massachusetts area is conducted. This study will identify the potential users of EMC. The determination if EMC is ready to be widely implemented to SMEs through the MEP is also investigated.

3.1 GOAL

SMEs play an important role in the development and implementation of new technologies. They serve as a primary vehicle for new technology transfer. Consequently, they play a major role in US economic growth as they pioneer this new technology.

This project researches past methods of transferring technology to SMEs. The EMC technology was used as a model to determine the effectiveness of the methods of technology transfer to SMEs. The data gathered has been used to assess the impact that the technology has on small businesses. An extensive study was conducted on users that are utilizing EMC technology in particular. Through this project, NIST will have a standardized method by which to transfer their EMC technology to manufacturing businesses.

In addition, a portable EMC demonstration site for further expansion into small to medium sized manufacturing businesses was created. The effectiveness and determination whether or not EMC is ready for the transfer to SMEs will also be

determined. There will also be an installation manual compiled that new users can use to understand and install EMC.

3.2 DELIVERABLES

A transferable demonstration site for the EMC technology is setup on a Bridgeport machine. This demonstration site will be available to SMEs interested in utilizing the EMC technology. Care was taken so that the machine will be able to run in its original state once the EMC has been disconnected.

There was sufficient documentation of the setup so that an installation and setup manual could be and was produced. This way, others who are interested in the EMC technology will have more information on it, and the technology can be more widely integrated into the small manufacturing community.

A list of potential users in the Massachusetts was produced through the screening of all metal working companies in the area. A customer profile was established and aids in the company selection.

Finally, and most importantly, research is conducted on users that are currently using the EMC. This includes determining the effects that EMC has on small manufacturers, their employees, and the impact on society due to the increased productivity. Matrices on economic development such as increase employment, increased sales, and decreased operation costs were examined.

4.0 METHODOLOGY

This section is to discuss the procedures that were followed to complete the objectives. The project objectives are to: 1) identify a practical means to transfer the EMC technology to SMEs; 2) determine the barriers that SMEs face in the technology transfer; 3) investigate and document the advantages and disadvantages of transferring new technology to industry using EMC as a case study; 4) determine if the EMC technology is transferable and will profit the end user. To accomplish this interviews of key individuals were conducted. The email lists for EMC users were also monitored on a daily basis. The comments were taken into consideration for the final determination of transferability of EMC technology. Finally, questionnaires were sent out to users of EMC.

4.1 THE CUSTOMER

One of the great tasks associated with technology transfer is recruiting companies to participate. The approach is a strategy that will capture the interest of the SME owners. This is a three-phase process that includes: finding the technology development, administering the technology transfer, and utilization of the new technology by the SMEs. The first step, finding the technology, is the EMC technology provided by NIST. The second step is essentially informing the SMEs of the technology, and then showing how it will benefit them. Some methods of informing the SMEs include demonstration sites, seminars, videos, mailing brochures, on-site presentations, newsletters, and the World Wide Web. This IQP will identify the best methods determined through research of the specified customers. It is unrealistic to say that all methods of informing the SMEs will be viable for any given technology, but the more methods used the better the chances

of the technology being transferred. The methods that are chosen through the research are presented later in the report.

One possible method is a demonstration site. The establishment of the demonstration site is retrofitting an existing Bridgeport CNC milling machine with the Enhanced Machine Controller program on a personal computer. Throughout the demonstration site setup, documentation of all steps was recorded, and an instruction manual was produced, see Appendix B.

4.2 DEMOGRAPHIC STUDY

The objective of a demographic study is to identify the growth and number of potential customers in the Massachusetts region. For the case of the EMC technology, the study was concentrated primarily on manufacturers of steel products. Those manufacturers that perform machining operations are specifically targeted. The American City Business Journals released a report on the status of the manufacturing sector. According to the report, the United States had 18.35 million manufacturing jobs in September 1999, equaling a market share of 14.24 percent. The only sectors that were larger were the services (39.24 million jobs) and retail trade (22.83 million). More than half of the nation's labor market added manufacturing jobs in the past year, and national manufacturing employment increased 0.84% during the same 12-month period. Employment rose from 18.44 million in October 1996 to 18.60 million in October 1999 (Goldstein, 1999).

This information is narrowed down to the Massachusetts region. The cities that have statistics are listed in the following table.

Table 4.1: Manufacturing Jobs in Massachusetts Cities

Rank	City	Non Farm Jobs	Manufacturing Jobs
1	Boston	1,920,700	221,200
2	Springfield	250,500	39,400

Some other interesting information is the number of Bridgeport milling machines that have been installed. This information is critical because the EMC technology is ideal for retrofitting an older Bridgeport machine. In 1968, Bridgeport Machines became part of Textron. The first N/C Series I machine, manufactured and assembled by Bridgeport, was introduced at the 1970 Machine Tool Show. Later in 1970, Bridgeport introduced the Series II machine, which is the big brother to the Series I. Since that time both the Series II machine and Numerical Control machines have been built in high volume. The production of Series I machines has exceeded the 350,000 mark. Typically, metal working shops are the primary buyers of such machines (Bridgeport, 2000).

4.3 CASE STUDIES

Documentation of how SMEs currently utilize the EMC technology is important to the development of EMC technology. A case study of how companies that have already adopted the technology benefit from EMC supports the transfer of EMC to future customers. EMC technology will be used as a test bed for this study. The above studies of EMC technology determine the future of this program and the transfer to prospective users.

4.4 QUESTIONNAIRES AND INTERVIEWS

The effects of EMC questionnaires and the interviews with retrofitting services in the Massachusetts area helped to determine the customer needs and other information that

measures the need of EMC technology. The interviews and questionnaires were used to gather information for the benchmarking study and the productivity. In addition, two other individuals were contacted both by phone and by email for information regarding the retrofitting of the Bridgeport machine with EMC. The first person is Fred Proctor, the inventor, and the second person is Matt Shaver. Mr. Proctor works at NIST, and continuously updates and monitors EMC's progress. Matt Shaver is an expert at retrofitting machines with the EMC technology. Mr. Shaver is also working on designing a control board that would fit several machines. The electronic mailing of questionnaires was directed towards current users. The questionnaires were sent to 15 key individuals who are important to the development of EMC and also to two email lists CAD_CAM_EDM_DRO@onelist.com and emc@nist.gov. Both email lists are used in information sharing about EMC and contain an undisclosed number of EMC users. Information such as time and money saved through the mailings was documented.

4.5 BENCHMARKING STUDY

A benchmarking study was done of retrofitting services in the New England area to assess the competition that a company would face if it only retrofits Bridgeport type machines with EMC. The study was to find out what types of retrofitting services were available, and what the cost would be to retrofit a Bridgeport type machine. The retrofitting services that were contacted were picked from the Thomas Register list. Since there were only X retrofitting services in the New England are all of them were contacted. Personnel from the contacted retrofitting services were interviewed over the telephone on the type of work their business does.

5.0 MARKET RESEARCH

Market research intends to study the demand for a new technology. This study also identifies competitors as well as customers. All metal working companies in the Massachusetts area are considered potential customers of the EMC technology. For this project, a profile of the ideal customer must be established. Therefore, considering only SMEs that employ a minimal number of personnel is established later in the report. The list must also contain a certain Standard Industrial Classification (SIC) Codes in order to be considered a metal working company. The methodologies chosen to complete this study are to first make out a customer profile, and then do a demographic study of SMEs in Massachusetts to identify the number of potential customers. A benchmarking study of retrofitting services in the same area was conducted to determine the competition a retrofitting service, specializing in EMC retrofits, would face. Once these were completed, a final examination of initial new technology users is conducted. The following details this study.

5.1 CUSTOMER PROFILE

The customer profile represents the ideal company to target for installation of the EMC technology. We have structured the customer profile by identifying several factors. These factors include:

- Number of Employees
- Number of Machines
- Type of Machines
- Product Description

The ideal customer will be a metalworking or potential CNC user that will benefit from the introduction of EMC. The EMC technology will give the customer an opportunity to economically use CNC capabilities that would otherwise be out of budget.

The customer profile that has been established is:

> An SME that provides business primarily in the machine tool or metal manufacturing industry will be chosen. The number of employees should be two or more and there should be two or more Bridgeport machines with BOSS controllers.

5.2 DEMOGRAPHIC STUDY RESULTS

The demographic study is important to the overall market analysis. The number of potential customers in the designated region will dictate whether or not there is demand for this new technology. The companies chosen are to meet the customer profile.

A list of company names, number of employees, and services provided are listed in Appendix E. This gives enough information about the companies in the Massachusetts area to produce the customer profile. The companies were selected based on their Standard Industrial Classification (SIC) Codes. Standard Industrial Classification codes are a widely accepted method of classifying businesses. Some useful codes in the search used are:

3544 Dies, Tool, Fixtures, and Injection Molds

3545 Machine Tool Accessories

3599 Machinery and equipment, commercial and industrial

The list has 1132 companies; of that number, 966 companies (85%) have fewer than twenty-five employees.

5.3 BENCHMARKING STUDY RESULTS

The retrofitting services that were contacted, by telephone, provided many different types of retrofitting. The type of retrofits that the companies perform ranges from only retrofitting mechanical components, to a complete overhaul including a new CNC controller and motors. A few companies would only retrofit certain types of machines; Bridgeport type machines were not included; and several other companies were not actually retrofitting services. Below is a table of the companies that perform retrofits on Bridgeport type machines, the specifics of retrofit, and the cost of the retrofit.

Table 5.1: Retrofitting Service Information

Company	Type of retrofit	Cost ($)
Babin Machine Tool	2-3 axis (mechanical)	12,000-17,000
Accurate Machinery Inc.	3 axis (full)	50,000-53,000
Machine Tool Technology	3 axis	9,000-10,000
U.S. Machine Tools Corp.	3 axis (full)	30,000
Machine Master	3 axis (controller)*	2,000

*Note: This is only a kit; the consumers must do the retrofit on their own

5.4 PRODUCTIVITY STUDY AND EVALUATION OF EMC

The productivity of the users that have implement EMC technology varies from user to user. Some users have had great increases in their productivity, whereas others have had only problems with EMC. A survey, see Appendix C, was sent out to both the CAD_CAM_EDM_DRO@onelist.com and emc@nist.gov, two email lists that deal with EMC technology, and several key people involved with EMC with questions about the productivity and accessibility of EMC.

Of the fifteen questionnaires sent out to key users, who are actively involved in the development of EMC, and the posting of the questionnaire to both the

CAD_CAM_EDM_DRO@onelist.com and emc@nist.gov email lists eight responses were received, eight responses were received. The respondents identified several advantages that EMC offers. These include:

1) greater capabilities
2) low cost of implementing EMC
3) ease of installation and use after exposure to EMC
4) new CNC capability

The capabilities that were mentioned in the responses were things such as the availability of more G-codes. The availability of more G-codes give EMC an advantage because that means that it is more likely to be able to run any given program. In addition, larger programs can be run because the only restriction on space is the amount of hard drive space in the computer. The ability to run larger programs allows more complex parts to be machined in less time. The time is reduced because the program does not have to be segmented to fit into the controller's memory space. Another capability that EMC provides is the ability to make common patterns easier is a very important quality in a software package. This means that the parts can be made faster and easier, leaving more time for larger jobs. This leads to increased productivity.

Low cost is one major advantage that EMC provides over other commercial machine controllers. If the user can implement EMC for a substantially less amount of money than a commercial controller that would definitely benefit the user. The money saved could be put towards materials for parts, and most likely reduce costs to the users clients, or increase earnings.

The easy of implementation, after exposure to EMC, is very important since EMC can control virtually any machine. This means that if the user has several machines he/she can implement EMC on however many of those machines the user wants to.

Therefore training for different controllers is eliminated. This would be extremely useful in larger machine shops.

The ability to upgrade a manual or NC machine to a CNC machine using the low cost EMC implementation would greatly increase productivity for the user. With the addition of CNC capabilities, the user could begin making parts more efficiently.

The responses showed only two major disadvantages of implementing and using EMC. These are:

1) difficult installation of Linux and RTLinux
2) current status of EMC

The major problem that virtually all of the users encountered with EMC was difficulty with Linux/RTLinux. Without prior experience with Linux, using both Linux and RTLinux becomes more difficult. Often this fact alone is enough to discourage a potential user. If the user can overcome the Linux operating system the installation and use of all of the EMC components becomes easier.

The current status of EMC is that it is in the developmental stage. Since EMC is still in the developmental stage it contains bugs. This is true of all software in the beginning stages. Before EMC reaches commercial quality it must go through constant testing. As with any beta software, at present EMC can be classified as beta software, it will not be perfect and may cause frustration to its users. The only way to remedy this through testing, usually through beta sites, and revision.

The users were also asked for other comments about EMC. The main responses that were received were:

1) EMC is good for someone who has time to experiment
2) the interactive ability to provide feedback

At present, EMC use is ideal for hobbyist or user who has the ability to experiment with the technology. This is essential. These beta users provide are crucial to the development of EMC. Without beta testing, such as is currently happening with EMC, the software would be useless. The feedback that the current users provide to the developers helps greatly in providing low bug software. In other words, EMC is growing to become the best it can be.

Obviously, EMC is still in the development stage, and it will take some time until a stable version with all of the capabilities that are needed will be ready. However, EMC remains an alternative to expensive controllers, for the users who have time to experiment with the technology. For the complete responses to the surveys, see Appendix C.

6.0 THE DEMONSTRATION SITE

The demonstration site consists of two main parts, the computer on which EMC runs, and the machine, a Bridgeport Series I, with the Bridgeport Operating System Software 5 (BOSS 5). For the construction of the demonstration site, the machine was retrofit with the computer such that EMC will control the machine instead of the BOSS 5 controller. In addition to the computer and the machine the retrofit requires the interface card (Servo To Go (STG) card).

6.1 COMPUTER SETUP

The computer that was used was a Pentium 166MHz with a 1.6GB hard drive and 32 MB RAM. The computer setup was fairly simple, although a major problem did arise during the setup. The problem was during the conversion from pure Linux to RTLinux (for more information on Linux see sections 2.3 and 2.4). The problem was that the Real Time patch would not compile. This essentially means that it would not install. The problem is that Linux is a very hardware intensive Operating System. This means that if there is a faulty part in the computer, the performance of the computer and Linux is affected. A faulty part is not exclusively one that doesn't work at all, but could simply contain a small error that would normally go undetected in Windows. The most common problem is faulty RAM.

Several different methods were used in attempt to fix this. These methods included transferring the hard drive to another computer. Unfortunately although the Real Time patch would compile, when the hard drive was returned to the original computer, would not work. The RAM in the computer was also replaced, which did not help either. Installation was attempted on several other equivalent computers, which also would not

work. This was due to another problem. This problem was simply an error in the installation instructions that were used. The error was that the instructions said to edit the boot file for Linux with a line that specified a certain amount of RAM. The amount of RAM that was specified in the instructions was different from the amount that was actually in the computer. Once this fact was discovered, the installation went through with no problems.

6.2 MACHINE RETROFIT

The first thing that was required for the retrofit was the computer with RTLinux and EMC installed on it. The next part of the retrofit was the design and construction of an interface board, or the purchase of one. There is a ready-made board that can be adapted for use with EMC, the STG card. It was determined that it would be more feasible, given the project and time constraints, to purchase the STG card. One problem with a home made interface board, was that it would only work with the specific machine that was being retrofit for this project.

Once the STG card was obtained, the wiring of the card to both the machine and the computer was determined. The only connection with the computer was through a special cable that had a standard DB-25 connector, a standard 25-pin parallel port connector, on one end and a DB-37 connector that connected to the STG card.

The wiring from the STG card to the machine was ascertained by using compiled data from the CAD_CAM_EDM_DRO@onelist.com and emc@nist.gov mailing list correspondence and other sources. Extensions were made for the connectors inside the BOSS 5 controller cabinet of the machine. This was done so that none of the machine's

wiring would be cut. Wire the proper length was made, and connected to the correct terminals.

Once all of the components were wired correctly, and the computer was connected to the STG card, the retrofit was completed. Unfortunately, once the retrofit was completed it was discovered that there was a problem with one of the machine's transformers, and the machine would not work. This being true, first hand knowledge that EMC actually works could not be had. For pictures of the retrofitting process, see Appendix D.

7.0 RESULTS AND DISCUSSION

The final findings for the IQP project will now be presented. This section analyzes the EMC technology by presenting information gained through interviews, results of questionnaires, and individual case studies of companies that utilize EMC.

7.1 ANALYSIS OF EMC

The Enhanced Machine Controller technology is a much-needed asset to the United States machine tool market. The implementation of EMC into SMEs that utilize computer numerical control gives companies the tools needed to stay ahead in a competitive market. The larger manufacturing companies are able to purchase expensive, high tech software packages or complicated CNC machinery with their higher purchasing budgets. In the past, the SME had to make do with older archaic CNC or manual machines. Now, with the EMC technology available as an open architecture system, the SME has the ability to capture back some of the metalworking market that was once lost to the larger competitors.

The EMC technology has its advantages and disadvantages and each will be discussed from a user standpoint. The advantages are simple: low cost, availability, user friendly interface, and flexibility. Some of the disadvantages of EMC technology are complicated installation, use of unfamiliar operating system, and still in developmental stage.

7.1.1 LOW COST

The EMC Technology can be obtained at no charge from ftp://ftp.isd.mel.nist.gov/pub/emc/emcsoft/. The Linux operating system is also available

free of charge. The costs that are associated with the use of EMC are the use of a personal computer, wiring, and a control board, all of which are at a fraction of the cost of implementing a competitor's CNC software or CNC machine. As for the machine, the cost is a case-by-case situation. For example in the case of the Series I Bridgeport used in the IQP project installation the only cost was the Bridgeport itself, which was donated for educational purposes. In other instances, a motor/motors may need to be replaced. The ball screws, ways, and lead screws, are all vital parts to machine accuracy may also need updating.

7.1.2 AVAILABILITY

The EMC software has been made available to any potential user by downloading the file to a personal computer and then installing the software on a Linux based operating system. Both of these programs can be obtained at ftp://ftp.isd.mel.nist.gov/pub/emc/emcsoft/ for EMC and http://www.linux.org/help/beginner/distributions.html for Linux.

7.1.3 USER FRIENDLY INTERFACE

Once the system is installed, the program becomes easy to use. The user can simply navigate through the control screen to command the machine to do a number of objectives. These range from executing rapid/feed traverse to sending complete tool paths through the computer.

EMC features open architecture, meaning the user can alter the software code any way he/she sees fit. This is an extremely valuable tool. If the user were to implement

EMC on several different machines, the different copies of EMC that were controlling the different machines could be customized for the use of the specific machine. Another possibility would be if the users only machined certain types of parts EMC could be customized to the specific needs of the part.

7.1.4 DIVERSE RETROFITTING CAPABILITY

The EMC technology can be retrofitted on any metalworking machine. The basic requirements are that the machine has/had CNC capabilities. The CNC components do not necessarily need to be in working order. If the machine has never had CNC capability, the retrofitter must also add the required components for a CNC machine. These components include motors, ball screws etc.

Another benefit is that the implementation costs will be reduced because off-the-shelve components will be available from multiple sources. Less engineering time will be required to integrate these components into systems. Training costs will be reduced because the operator interface can be customized to emulate widely used and familiar operating controls. Maintenance costs will be lower due to multi-vendor sourcing, reduced lead-time for components, and inventory reduction (Proctor 1999).

7.1.5 COMPLICATED INSTALLATION

The installation of EMC has a major downfall. There is no standard installation or components to install as of this report . That is for every machine there is a unique procedure needed to install the EMC technology. Each machine receives information differently, and there is no standardization of a control board to serve that purpose.

Troubleshooting can only be done by consulting a news group that caters to EMC users. The cables and wiring are also unique for each setup.

7.1.6 LINUX OS

The Linux OS is needed for its real time capability. Without it, the machine would not be able to receive real time information and an inaccurate part would result. The problem with the Linux OS is that the users must learn the new working environment. Personal computers are likely to have a version of Windows installed on them. The transition from Windows to Linux can be confusing and time consuming.

7.1.7 DEVELOPMENTAL STAGE

The EMC software is continuously updated by the recommendations from beta installations that have been conducted. Several test beds have been established and are monitored by NIST. They include Shaver Engineering (Gaithersburg, MD) and Flat Plate Inc. (York, PA). Once a version of EMC is installed onto a PC, an update may need to be obtained for newer features and enhanced capabilities.

7.2 INTERVIEW RESULTS

The information gathered through meeting with Fred Proctor and Matt Shaver will now be presented. Fred Proctor works in the Intelligent Systems Division of NIST. He is the person that has been continually updating and monitoring the EMC progress. One of Mr. Proctor's tasks is to receive feedback from key individuals such as Matt Shaver. Other feedback is also received through the email lists previously stated. Mr.

Proctor is optimistic of the EMC future as he also is learning the process of machining. Matt Shaver runs a business of retrofitting machines with the EMC program, and can be consulted through the <CAD_CAM_EDM_DRO@onelist.com> email list.

7.3 QUESTIONNAIRE RESULTS

The questionnaires that were sent out to the current EMC users provided some valuable insight into the actual benefits and problems of EMC, and the transfer of EMC technology. Although there was not an enormous response, the mailing to the CAD_CAM_EDM_DRO@onelist.com email list sparked a flame war, and some valuable viewpoints were expressed. In addition, the responses that were received contained both many different responses, and good suggestions about EMC. For more information on the results of the questionnaires, see section 5.4. It is obvious from the results of the questionnaires that EMC is an innovative technology that, although it is still in the development stages, is very powerful and important.

7.4 TECHNOLOGY TRANSFER

Technology plays an essential role in today's world. With the popularization of the computer and the Internet, information exchange has increased dramatically. In this way so has technology transfer. To keep the flow of technology from the laboratory to the user, the technology must be transferred. See section 2.2 for more information on technology transfer.

The government has greatly contributed to both the creation of technology, and to the transfer of technology. Many different organizations, mainly not for profit, have

arisen to facilitate the transfer of technology. This ranges from changing a company over from paper records to computerized records, to helping machine shops get better machines, or simply showing the company how to improve its overall productivity.

7.5 REAL WORLD ISSUES WITH EMC

EMC is a good alternative to expensive controllers and other such software however, other products are still being purchased. Part of this is due to the simple lack of exposure of EMC to the commercial market, and because EMC is still in its infancy. A major roadblock that many EMC users encounter is the interface between the PC and the machine. While there is a product on the market that can be used, the STG card, it is expensive. If a generic card were to be produced that would work with EMC and connect to any machine, or a design of one that could be constructed by the user, EMC would become much more popular and easy to implement.

Another problem that EMC users first encounter is RTLinux. RTLinux is not a widely used operating system, and therefore many problems can arise and discourage the user from implementing EMC. The idea of creating easy RTLinux/EMC installation disk has been thoroughly discussed by the EMC users and prospective EMC users on the previously mentioned email lists. Unfortunately, so far no product has been produced.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The objectives of this report were to: 1) evaluate current methods of transferring new technology from federal labs to SMEs and determine the best method for transferring EMC technology; 2) determine the effectiveness of EMC in industry and whether or not it is ready for transferring; 3) enable Massachusetts MEP to use a demonstration site for the transferring of EMC technology. Our conclusions and recommendations are contained in this section of the report.

8.1 IMPLEMENTING EMC TECHNOLOGY

The implementation of EMC is a two-fold process. The first step is to establish a need for the technology through customer wants and job requirements. The next step is to introduce the interested customer to a working demonstration site of EMC. This latter requirement can be accomplished through video or live presentation. The use of brochures, trade shows, and mailing lists can serve as an appropriate medium for the dissemination of the EMC technology. As the metal working community is small, word of mouth will spread informing other prospective users.

The effectiveness of EMC at this stage is still premature to assess. The EMC technology is still in the developmental stage and has not been widely implemented. Through the data gathered from email lists and questionnaires, it was determined that the projected outlook of this technology is a productive, adaptable, and versatile program. The fact that EMC is free sets it apart from other machine control software. A market of standard items such as control boards and wiring would enhance the EMC technology immensely. At this time, EMC may not be the ideal model to transfer into an SME. Due to its installation drawbacks, and lack of guaranteed support, the SME will be taking a

chance on the success of EMC in the work place. Many hobbyists utilize the EMC technology since it is free, and therefore are the primary users. NIST has been in constant contact with a few of these key individuals to continue the EMC technology success.

8.2 FUTURE WORK

This IQP looked at several aspects of EMC and technology transfer. However, since EMC is such a new technology there is not an abundance of information about it. In addition, due to the problems with the Bridgeport milling machine the demonstration site was not completed. The future work that stems from this project will expand the goal of implementing EMC and providing the technology to SMEs. Through the relations of Massachusetts MEP and NIST, this goal is reachable.

Work that could be completed in a continuation of this project includes: research on other avenues for the transfer of EMC technology, completion of the demonstration site, and a focus study for further EMC productivity research. Since the base research on current technology transfer methods for EMC has been completed, research on new methods of transferring EMC technology should be completed. For the demonstration site completion, complete implementation of EMC and verification must be done.

The demonstration site is in a position to be finished. The technical expertise that a professional, such as Matt Shaver, could provide will greatly help this completion. The recruitment of actual SMEs for a focus study that will participate in a transfer of EMC needs to be established. Research with the focus group should begin before the implementation of EMC, and the researchers should document all aspects of how EMC affects the given SMEs. The time and effort Massachusetts MEP and NIST has put into

this project is only the first step in what will be a successful accomplishment of transferring a new technology from federal laboratories to SMEs.

APPENDIX A: LIST OF ABBREVIATIONS

MEP	Manufacturing Extension Partnership
NIST	National Institute of Standards and Technology
EMC	Enhanced Machine Controller
SME	Small and Medium Sized Enterprises
CNC	Computer Numerical Control
PC	Personal Computer
RTLinux	Real Time Linux

APPENDIX B: REAL TIME LINUX AND EMC INSTALLATION GUIDE

Compiled by Karl Klemm
From:
The Enhanced Machine Controller (Proctor, 1999)
EMC Installation Instructions (ktmarketing, 1999)
Onelist correspondence

SYSTEM REQUIREMENTS:

- IBM PC-compatible, 386 or higher (Pentium recommended), with these specs:
  - standard AT keyboard
  - serial or PS/2 mouse
  - video board and monitor, as supported by your Linux distribution
  - 800 megabytes or larger hard disk (IDE recommended; SCSI not tested, but should work)
  - 32 megabytes or greater RAM
  - 3-1/2" floppy drive, for booting Linux during install and copying Real-Time Linux patch
  - CD-ROM drive, for loading Linux distribution (IDE ATAPI recommended; others should work)

ADDITIONAL MATERIALS:

- Linux distribution, typically on a CD-ROM
- Real-Time Linux .tgz patch file, typically downloaded to a floppy. These patches have been modified to enable the use of floating point math in real-time code, which is required for the EMC.

INSTALLATION:

1. Boot up the PC from the boot floppy accompanying your Linux distribution. If no such floppy came ready-made, you can build one following the instructions that came with your distribution. With Red Hat Linux, the dosutils\rawrite.exe on the CD-ROM is used. The program prompts for the destination floppy (e.g., A) and the disk image to be copied to floppy. The image to use is images\boot.img on the CD-ROM.

2. Follow the installation instructions prompted by the boot program. If you have a manual, follow the printed instructions! After installation is complete, the computer will be rebooted. You should end up with a PC that boots Linux when it's powered up. If not, see the Troubleshooting section.

3. Log in as "root", using the password you set up when you installed Linux. If you want, start X Windows via:

```
startx
```

   If this doesn't work, don't despair. You can get this working later.

4. Go to the base source directory.

```
cd /usr/src
```

5. Mount the floppy on which you have the Real-Time Linux .tgz patch file, copy the file over to the base source directory, and unmount the floppy. In the example below, the .tgz file is shown with a V for your version (e.g., 5, 6) and XX for kernel (e.g., 27, 33). Replace these with the actual numbers for your distribution and patch.

```
mount /dev/fd0 /mnt/floppy
cp /mnt/floppy/release9J.tgz /usr/src
umount /mnt/floppy
```

6. Unpack the Real-Time Linux patch. This will create the rtl/ directory.

```
tar xzvf release9J.tgz
```

7. Go to the base linux source directory.

```
cd /usr/src/linux
```

   Apply the Real-Time Linux patch by following the instructions in the README file located in the rtlinux directory. Capture the output to a file, so you can see if the patch worked. This will be something like:

```
patch -p1 < /usr/src/kernel_patch 1> patch.out 2> patch.err
```

The patch.out file will contain normal diagnostic output; the patch.err file will contain errors. Inspect them for signs like "hunk #1 failed". All parts of the patch should have been installed with no failures. If you do have failures, it means that the kernel and patch don't match. Consult the Real-Time Linux web page rtlinux.cs.nmt.edu/~rtlinux for more information.

8. Configure Linux by running

```
make config OR make menuconfig
```

   If you are running X Windows (i.e., startx worked when you ran it after logging in), you can configure Linux by running

```
make xconfig
```

   The configuration program will let you customize hardware drivers and other operating system components. Unless you know what you are doing, you can leave everything at their defaults.

9. Create the dependencies and clean up the files in preparation for building the kernel.

```
make dep ; make clean
```

10. Build the kernel. This will take quite a while, and will generate lots of diagnostics output as the Linux and Real-Time Linux source code is compiled.

```
make zImage
```

11. Build the kernel modules, among which are the real-time scheduler and FIFO communication queues.

```
make modules
```

12. Install the kernel modules in the standard place Linux looks for them.

```
make modules_install
```

13. These two modules can be loaded automatically when you boot up by putting them in the local boot script, typically in `/etc/rc.d/rc.local`. You can put the entries at the end of the file, e.g.,

```
# install RT-Linux modules
insmod /usr/src/rtl/modules/rtl_fifo
insmod /usr/src/rtl/modules/rtl_sched
```

14. Go to the directory in which boot information is stored. On Red Hat Linux distributions, this is /boot.

```
cd /boot
```

15. Copy the newly-compiled kernel to the boot directory, overwriting the original one.

```
cp /usr/src/linux/arch/i386/boot/zImage /boot/vmlinuz
```

16. Configure shared memory communication by editing /etc/lilo.conf, and adding a line specifying the amount of RAM to be used by Linux. This is a typical default entry in `/etc/lilo.conf`:

```
boot=/dev/hda
map=/boot/map
install=/boot/boot.b
prompt
timeout=50
image=/boot/vmlinuz
 label=linux
root=/dev/hda1
read-only
```

Add a line after the last entry for the image, to specify an amount of memory 1 megabyte less than your total amount of physical memory. The extra 1 megabyte will be used for EMC communication. For a 32-megabyte system, this line is `append="mem=31m",` as shown in bold below:

```
boot=/dev/hda
map=/boot/map
install=/boot/boot.b
prompt
timeout=50
image=/boot/vmlinuz
 label=linux
root=/dev/hda1
read-only
append="mem=31m"
```

For a 64-megabyte system, this line is append="mem=63m", as shown in bold below:

```
boot=/dev/hda
map=/boot/map
install=/boot/boot.b
prompt
timeout=50
image=/boot/vmlinuz
label=linux
root=/dev/hda1
```

```
read-only
append="mem=63m"
```

If you are interested in using shared memory for your own programming, see Using Shared Memory in Real-Time Linux for details.

17. Run the Linux Loader (LILO) to configure the boot loader to use the new kernel and to boot with 1 megabyte of shared memory set aside.

```
/sbin/lilo
```

18. Reboot to run the new kernel.

```
/sbin/reboot
```

19. Log back in as root, and verify that the real-time modules loaded properly from the local boot script.

```
/sbin/lsmod
```

You should see something like this:

Module	Pages	Used by
rtl_sched	1	0
rtl_fifo	2	0

20. Go to the Real-Time Linux test program directory.

```
cd /usr/src/rtlinux-0.V-2.0.XX/testing
```

21. Read the README file and create the special files for FIFO communication.

```
mknod /dev/rtf0 c 63 0
mknod /dev/rtf1 c 63 1
mknod /dev/rtf2 c 63 2
mknod /dev/rtf3 c 63 3
```

22. Go to the 2-tasks testing directory and build the test example.

```
cd /usr/src/rtlinux-0.V-2.0.XX/testing/2tasks
make
```

23. Now run the test example.

```
/sbin/insmod ./rt_process.o
./app
```

You should see something like this:

FIFO 1: Frank
FIFO 2: Zappa
(more of the same)

If you got this far, congratulations! Linux and Real-Time Linux are installed and configured. Now you can go to the EMC software site and start on the next phase, building the controller.

SETTING UP EMC

The EMC is configured with files that are read at startup and used to override the compiled defaults. No real controller will likely use the compiled defaults, so you will certainly need to edit at least some of these files to reflect the specifics of your machine.

There are four files: emc.ini, emc.nml, tool.tbl, and rs274ngc.var. The first, emc.ini, contains all the machine parameters such as servo gains, scale factors, cycle times, units, etc. and will certainly need to be edited. emc.nml contains communication settings for shared memory and network ports you may need to override on your system, although it is likely that you can leave these settings alone. tool.tbl contains the tool information such as which pocket contains which tool, and the length and diameter for each tool. rs274ngc.var contains variables specific to the RS-274-NGC dialect of NC code, notably for setting the persistent numeric variables for the nine work coordinate systems. The specific formats of each of these files is detailed in the following sections.

- **MACHINE CONFIGURATION FILE EMC.INI**

The machine configuration file emc.ini follows the Microsoft INI file format, in which values are associated with keywords on single lines, perhaps in sections denoted with square brackets, e.g.,

```
[SECTION]

; COMMENT
SYMBOL = VALUE
```

Everything from the first non-whitespace character after the = up to the end of the line is passed as the value, so you can embed spaces in string symbols if you want to.

You can edit the values for each keyword in any text editor. The changes won't take effect until the next time the controller is run. The file should be called emc.ini, but the name can be overriden using a command line argument to the controllers. See the section "Starting Up" for information on how to do this. The following sections detail each section of the configuration file, using sample values for the configuration lines.

[EMC] Section

The [EMC] section contains general parameters for the whole controller. These are:

```
VERSION = $Revision: 1.14 $
```

The version number for the INI file. This is automatically updated when using the Revision Control System, which looks for the `$Revision: 1.14 $` string and

appends the revision number. If you want to edit this manually just change the number and leave the other tags alone.

MACHINE = My Controller

This is the name of the controller, which is printed out when it runs. You can put whatever you want here.

[TASK] Section

The [TASK] section contains general parameters for EMCTASK, which includes primarily the NC language interpreter and the sequencing logic for sending commands to EMCMOT and EMCIO.

CYCLE_TIME = 0.100

The period, in seconds, at which EMCTASK will run. You can make this as small as you want to increase the throughput. Making it 0.0 or a negative number will tell EMCTASK not to sleep at all. Ultimately the system loading will limit the effective throughput.

[TRAJ] Section

The [TRAJ] section contains general parameters for the trajectory planning module in EMCMOT.

AXES = 3

The number of controlled axes in the system.

LINEAR_UNITS = 0.03937007874016

The number of linear units per millimeter. For systems executing in native English (inch) units, this value is as shown above. For systems executing in native millimeter units, this value is 1. This does not affect the ability to program in English or metric units in NC code. It is used to determine how to interpret the numbers reported in the controller status by external programs.

ANGULAR_UNITS = 1.0

The number of angular units per degree. For systems executing in native degree units, this value is as shown above. For systems executing in radians, this value is 0.01745329252167, or PI/180.

CYCLE_TIME = 0.010

The period in seconds at which trajectory calculations are performed. This is a multiple of the period at which servo calculations are performed, as set in the [AXIS_#] CYCLE_TIME entry. Trajectory calculations are called at multiples of the servo period to plan linear or circular motion in Cartesian space. These values are interpolated at the servo period and run through the inverse kinematics.

DEFAULT_VELOCITY = 1.0

The initial velocity used for axis or coordinated axis motion, in user units per second.

DEFAULT_ACCELERATION = 100.0

The initial acceleration used for axis or coordinated acis motion, in user units per second per second.

MAX_VELOCITY = 5.0

The maximum velocity for any axis or coordinated move, in user units per second.

MAX_ACCELERATION = 100.0

The maximum acceleration for any axis or coordinated axis move, in user units per second per second.

[AXIS_#] Sections

The [AXIS_0], [AXIS_1], etc. sections contains general parameters for the individual axis control modules in EMCMOT. The
axis section names begin numbering at 0, and run through the number of axes specified in the [TRAJ] AXES entry minus 1.

TYPE = LINEAR

The type of axes, either LINEAR or ANGULAR. Values for the position of LINEAR axes are in the units (per millimeter) specified in the [AXIS_#] UNITS entry. Values for the position of ANGULAR axes are in the units (per degree) specified in the same entry.

UNITS = 0.03937007874016

Units per millimeter for a LINEAR axis, as defined in the [AXIS_#] TYPE section, or units per degree for an ANGULAR axis as defined in the same section.

The following parameters P, I, D, FF0, FF1, FF2 are used by the servo compensation algorithm to optimize performance while tracking trajectory setpoints. See Tuning Servos for information on setting up a servomotor system.

P = 50

The proportional gain for the axis servo. This value multiplies the error between commanded and actual position in user units, resulting in a contribution to the computed voltage for the motor amplifier. The units on the P gain are volts per user unit.

I = 0

The integral gain for the axis servo. The value multiplies the cumulative error between commanded and actual position in user units, resulting in a contribution to the computed voltage for the motor amplifier. The units on the I gain are volts per user unit-seconds.

D = 0

The derivative gain for the axis servo. The value multiplies the difference between the current and previous errors, resulting in a contribution to the computed voltage for the motor amplifier. The units on the D gain are volts per user unit per second.

FF0 = 0

The 0-th order feedforward gain. This number is multiplied by the commanded position, resulting in a contribution to the computed voltage for the motor amplifier. The units on the FF0 gain are volts per user unit.

FF1 = 0

The 1st order feedforward gain. This number is multiplied by the change in commanded position per second, resulting in a contribution to the computed voltage for the motor amplifier. The units on the FF1 gain are volts per user unit per second.

FF2 = 0

The 2nd order feedforward gain. This number is multiplied by the change in commanded position per second per second, resulting in a contribution to the computed voltage for the motor amplifier. The units on the FF2 gain are volts per user unit per second per second.

CYCLE_TIME = 0.001

This is the period in seconds at which servo calculations will run. The values can be different between different axes, and the lowest will be used for all. This ensures that the calculations will occur at least as fast as they are specified here. The value should be an integer submultiple of the trajectory cycle time specified in the [TRAJ] CYCLE_TIME entry, so that an integer number of interpolations will occur. If this is not the case the times will be forced so that the interpolation interval is the next highest integer.

INPUT_SCALE = 40000 0

These two values are the scale and offset factors for the axis input from the raw feedback device, e.g., an incremental encoder. The second value (offset) is subtracted from raw input (e.g., encoder counts), and divided by the first value (scale factor), before being used as feedback. The units on the scale value are in raw units (e.g., counts) per user units (e.g., inch). The units on the offset value are in raw units (e.g., counts).

Specifically, when reading inputs, the EMC first reads the raw sensor values. The units on these values are the sensor units, typically A/D counts, or encoder ticks. These units, and the location of their 0 value, will not in general correspond to the quasi-SI units used in the EMC. Hence a calling is done immediately upon sampling:

input = (raw - offset) / scale

The value for scale can be obtained analytically by doing a unit analysis, i.e., units are [sensor units]/[desired input SI units]. For example, on a 2000 counts per rev encoder, and 10 revs/inch gearing, and desired units of mm, we have

[scale units]=2000[counts/rev]*10[rev/inch]*1/25.4[inch/mm]=787.4 counts/mm

and, as a result,

input [mm] = (encoder [counts] - offset [counts]) / 787.4 [counts/mm]

Note that the units of the offset are in sensor units, e.g., counts, and they are pre-subtracted from the sensor readings. The value for this offset is obtained by finding the value of counts for which you want you user units to read 0.0. This is normally accomplished automatically during a homing procedure.

OUTPUT_SCALE = 1 0

These two values are the scale and offset factors for the axis output to the motor amplifiers. The second value (offset) is subtracted from the computed output (in volts), and divided by the first value (scale factor), before being written to the D/A converters. The units on the scale value are in true volts per DAC output volts. The units on the offset value are in volts. These can be used to linearize a DAC.

Specifically, when writing outputs, the EMC first converts the desired output in quasi-SI units to raw actuator values, e.g., volts for an amplifier DAC. This scaling looks like:

raw = (output - offset) / scale

The value for scale can be obtained analytically by doing a unit analysis, i.e., units are [output SI units]/[actuator units]. For example, on a machine with a velocity mode amplifier such that 1 volt results in 250 mm/sec velocity, we have:

[scale units] = 250 [mm/sec] / 1 [volts] = 250 mm/sec/volt

and, as a result,

amplifier [volts] = (output [mm/sec] - offset [mm/sec]) / 250 [mm/sec/volt]

Note that the units of the offset are in user units, e.g., mm/sec, and they are pre-subtracted from the sensor readings. The value for this offset is obtained by finding the value of your output which yields 0.0 for the actuator output. If the DAC is linearized, this offset is normally 0.0.

The scale and offset can be used to linearize the DACs as well, resulting in values that reflect the combined effects of amplifier gain, DAC non-linearity, DAC units, etc. To do this, follow this procedure:

a. Build a calibration table for the output, driving the DACs with a desired voltage and measuring the result, e.g.,

RAW	MEAS
-10	-9.93
-9	-8.83
0	-0.03
1	0.96
9	9.87
10	10.87

b. Do a least-squares linear fit to get coefficients a, b such that

meas = a * raw + b

c. Note that we want raw output such that our measured result is identical to the commanded output. This means

cmd = a * raw + b
raw = (cmd - b) / a

As a result, the a and b coefficients from the linear fit can be used as the scale and offset for the controller directly.

MIN_LIMIT = -1000

The minimum limit (soft limit) for axis motion, in user units. When this limit is exceeded, the controller aborts axis motion.

MAX_LIMIT = 1000

The maximum limit (soft limit) for axis motion, in user units. When this limit is exceeded, the controller aborts axis motion.

MIN_OUTPUT = -10

The minimum value for the output of the PID compensation that is written to the motor amplifier, in volts. The computed output value is clamped to this limit. The limit is applied before scaling to raw output units.

MAX_OUTPUT = 10

The maximum value for the output of the PID compensation that is written to the motor amplifier, in volts. The computed output value is clamped to this limit. The limit is applied before scaling to raw output units.

FERROR = 1000

The maximum allowable following error, in user units. If the difference between commanded and sensed position exceeds this amount, the controller disables servo calculations, sets all the outputs to 0.0, and disables the amplifiers.

The following polarity values determine how inputs are interpreted and how outputs are applied. They can usually be set via trial-and-error since there are only two possibilities. The EMCMOT utility program USRMOT can be used to set these interactively and verify their results so that the proper values can be put in the INI file with a minimum of trouble.

ENABLE_POLARITY = 0

The polarity for enabling the amplifiers. Set this to 0 or 1 for the proper polarity. This value can be determined by following all the electronics back from the amplifier, through any driver circuitry, etc. or it can be set through a simple trial-and-error. Normally, for amplifiers which are enabled active-low (0 volts enables), this is a 0.

MIN_LIMIT_SWITCH_POLARITY = 1

The polarity for detecting minimum-travel hardware limit switch trips. Set this depending on how your switches are wired up to the digital inputs on the I/O board.

MAX_LIMIT_SWITCH_POLARITY = 1

The polarity for detecting maximum-travel hardware limit switch trips. Set this depending on how your switches are wired up to the digital inputs on the I/O board.

HOME_SWITCH_POLARITY = 1

The polarity for detecting homing switch trips. Set this depending on how your switches are wired up to the digital inputs on the I/O board.

HOMING_POLARITY = 1

The direction in which homing moves are initiated. 0 means in the negative direction, 1 means in the positive direction.

FAULT_POLARITY = 1

The polarity for detecting amplifier faults. Set this to 0 or 1 depending upon how the amplifier sets the logic level for its fault condition.

The following entries are used to set the parameters for the DC servomotor simulations. These are only used when running the EMC in simulation.

TORQUE_UNITS = OZ_IN

The units used to interpret subsequent values for ROTOR_INERTIA and DAMPING_FRICTION_COEFFICIENT. This can be OZ_IN for ounce-inches, LB_FT for pound-feet, or N_M for newton-meters.

ARMATURE_RESISTANCE = 1.10

The resistance, in ohms, of the motor.

ARMATURE_INDUCTANCE = 0.0120

The inductance, in henries, of the motor.

BACK_EMF_CONSTANT = 0.0254

The back EMF constant, or torque constant, in volts per radian per second.

ROTOR_INERTIA = 0.0104

The rotor inertia, in torque units * seconds2.

DAMPING_FRICTION_COEFFICIENT = 0.083

The damping coefficient, in torque units per radian per second.

SHAFT_OFFSET = 0

The angular offset, in radians, between the the motor initial position and the encoder initial position. Normally this is 0, but can be made any arbitrary value if the simulated motor shaft position is interpreted as the actual axis position and should be something other than 0 when the encoder reports 0.

REVS_PER_UNIT = 10

The amount of motor shaft revolutions per user unit of position. For example, for a 1/10 inch lead screw, where 10 rotations equals 1 inch, this would be 10.

The following entry is used to set the parameters for the amplifier simulations. These are only used when running the EMC in simulation.

AMPLIFIER_GAIN = 1

The gain of the amplifier, which multiplies the input voltage to generate an output voltage which drives the motor.

MAX_OUTPUT_CURRENT = 10

The maximum output current of the amplifier, in amps.

LOAD_RESISTANCE = 1.10

The resistance, in ohms, of the load on the amplifier. This is normally the same as the motor armature resistance, but it may not be, for example, if there is additional resistive load between the amplifier and the motor itself.

The following entry is used to set the parameters for the encoder simulations. These are only used when running the EMC in simulation.

COUNTS_PER_REV = 4096

The number of encoder counts per motor shaft revolution. If there is gearing between the encoder shaft and the motor shaft, this value should include this.

[EMCIO] Section

The [EMCIO] section contains control values and setup parameters for the digital and analog I/O points in EMCIO.

The following entries set general parameters for the I/O controller.

CYCLE_TIME = 0.100

The period, in seconds, at which EMCIO will run. You can make this as small as you want to increase the throughput. Making it 0.0 or a negative number will tell EMCIO not to sleep at all. Ultimately the system loading will limit the effective throughput.

TOOL_TABLE = tool.tbl

The file which contains tool information. The format of the file is

POC	FMS	LEN	DIAM	COMMENT
1	1	0	0	
2	2	0	0	

where the first line is a comment (in this case the name of the columns), and the subsequent lines contain the pocket number in which the tool is located, the tool ID of the tool itself, the length, the diameter, and an optional comment. The length and diameter are in user units.

The following entries set parameters for spindle control.

SPINDLE_OFF_WAIT = 1.0

How long, in seconds, to wait after the spindle has been turned off before applying the brake.

SPINDLE_ON_WAIT = 1.5

How long, in seconds, to wait after the spindle brake has been released before turning the spindle on.

The following entries set the bit indices for the digital I/O so that the controller knows the mapping to I/O point wiring. The indices start at 0 for the least significant bit in the digital I/O map. See Setting up the External Interfaces for information on interfacing I/O boards to the software.

ESTOP_SENSE_INDEX = 1

The location of the input bit which is used to detect whether the system is in ESTOP.

LUBE_SENSE_INDEX = 2

The location of the input bit which is used to detect whether the lubrication level is OK or low.

SPINDLE_FORWARD_INDEX = 1

The location of the output bit which is used to drive the spindle forward. Only applicable to manual spindles.

SPINDLE_REVERSE_INDEX = 0

The location of the output bit which is used to drive the spindle in reverse. Only applicable to manual spindles.

MIST_COOLANT_INDEX = 6

The location of the output bit which is used to turn mist coolant on or off.

FLOOD_COOLANT_INDEX = 7

The location of the output bit which is used to turn flood coolant on or off.

SPINDLE_DECREASE_INDEX = 8

The location of the output bit which is used to decrease the spindle speed. Only applicable to manual spindles.

SPINDLE_INCREASE_INDEX = 9

The location of the output bit which is used to increase the spindle speed. Only applicable to manual spindles.

ESTOP_WRITE_INDEX = 10

The location of the output bit which is used to cause an ESTOP.

SPINDLE_BRAKE_INDEX = 11

The location of the output bit which is used to engage or release the spindle brake.

The following entries set the polarities for the digital I/O points. These can be set by trial-and-error, or by noting the levels and any inverting done by the electronics between the sensors and actuators and the electronics.

ESTOP_SENSE_POLARITY = 1

The polarity of the sensed estop input bit.

LUBE_SENSE_POLARITY = 1

The polarity of the sensed lube level bit.

SPINDLE_FORWARD_POLARITY = 0

The polarity of the sensed spindle forward bit.

SPINDLE_REVERSE_POLARITY = 0

The polarity of the sensed spindle reverse bit.

MIST_COOLANT_POLARITY = 0

The polarity of the sensed mist coolant bit.

FLOOD_COOLANT_POLARITY = 0

The polarity of the sensed flood coolant bit.

SPINDLE_DECREASE_POLARITY = 1

The polarity of the sensed spindle decrease bit.

SPINDLE_INCREASE_POLARITY = 1

The polarity of the sensed spindle increase bit.

ESTOP_WRITE_POLARITY = 1

The polarity of the sensed estop activation bit.

SPINDLE_BRAKE_POLARITY = 0

The polarity of the sensed spindle brake bit.

Using the USRMOT Motion Utility

USRMOT is an interactive text-based utility that is used to set and test motion parameters for the EMCMOT motion controller. To use USRMOT, first run EMCMOT standalone (yourprompt> represents whatever your system prompt is):

```
yourprompt> emcmot
```

In another window, run the USRMOT utility:

```
yourprompt> usrmot
motion>
```

The motion> prompt is displayed by USRMOT when it runs. Entering a blank line lets you see the status:

```
motion>
mode:           free
cmd echo:       0
split:          0
heartbeat:      605
compute time:   0.014992
traj time:      0.200000
servo time:     0.020000
interp rate:    10
axes enabled:   0           0           0
cmd pos:        0.000000    0.000000    0.000000
act pos:        0.000000    0.000000    0.000000
velocity:       10.000000
accel:          100.000000
id:             0
depth:          0
active depth:   0
inpos:          1
vscales:        Q: 1.00 X: 1.00 Y: 1.00 Z: 1.00
logging:        closed and stopped, size 0, skipping 0, type 0
homing:         ---
enabled:        DISABLED
```

- **TUNING SERVOS**

For a detailed description of tuning servos, see the following references:

1. Benjamin C. Kuo, Automatic Control Systems, Fourth Edition.

DEFINING COMPLEX KINEMATICS

By default the EMC assumes trivial Cartesian kinematics in which X, Y, and Z coordinates map directly to motors 0, 1, and 2. You can define more complex

kinematics, for example for a robot, by replacing the default kinematics functions with your own.

The C language declaration for the kinematics, found in emcmot.h, is

```
#include "posemath.h" /* PmPose */

extern int forwardKinematics(double * joints, PmPose * pos);
extern int inverseKinematics(PmPose pos, double * joints);
```

You can replace these with any kinematics you like, provided they conform to these declarations. Replace the file trivkins.o from the link line that builds emcmot with your own, and rerun the compiler.

- **SETTING UP THE EXTERNAL INTERFACES**

The interface between motion control and discrete I/O control points and the software is declared in the C language header file extintf.h.

For example, one of the external APIs is

```
/*
        extDacWrite(int dac, double volts)

        writes the value to the DAC at indicated dac, 0 .. max DAC - 1.
        Value is in volts. Returns 0 if OK, -1 if dac is out of range.
*/
extern int extDacWrite(int axis, double voltage);
```

which is called by the motion controller to output a voltage to the motor velocity amplifiers. For a particular digital-to-analog
converter board, the function would be implemented as something like:

```
/* specific function to output voltage for my board */
        int myBoardDacWrite(int axis, double voltage)
        {
        short int vout;

        vout = (short int) (voltage / 10.0 * 0xFFFF);

        _outw(0x280 + axis, vout);

        return 0;
        }

/* mapping of my function to API */
```

```
int extDacWrite(int axis, double voltage)
        {
        return myboardDacWrite(axis, voltage);
        }
```

Another external API is

```
/* reads value of digital input at index, stores in value */
        extern int extDioRead(int index, int *value);
```

which is called by the discrete I/O controller to read a digital input into the 'value' variable, from the I/O point at the specified
'index'. For a particular digital I/O board, the function would be implemented as something like:

```
/* specific function to input value from myboard */
        int myBoardDioRead(int index, int *value)
        {
                unsigned char mask;

                mask = 1 << index % 8;

                *value = (_inb(0x380 + index / 8) & mask) ? 1 : 0;

                return 0;
        }

/* mapping of my function to API */
        int extDioRead(int index, int *value)
        {
        return myboardDioRead(index, value);
        }
```

The code above is referred to as a "wrapper" for myboard. NIST has written wrappers for some specific boards. See Wrapped Hardware for more information.

- **STARTING UP**

  The EMC can be started up by scripts, which take command line arguments for the various files if their names are to be overriden. The scripts should be run in the directory in which the configuration file are located, unless they are overriden with paths to alternate files. The conventional practice is to create a script file called run.emc based on one of the example run scripts, and run it in the top-level emc directory where the configuration files emc.ini and emc.nml are located. The syntax is:

  ./run.sunos5

APPENDIX C: QUESTIONNAIRES

Below are the responses to the questionnaire that was sent to both the CAD_CAM_EDM_DRO@onelist.com mailing list and also the emc@nist.gov mailing list. The CAD_CAM_EDM_DRO list discusses many things having to do with machining, one of which is EMC. The nist emc list discusses exclusively EMC. The responses have not been edited at all, so any spelling and grammar mistakes are due to the respondent. The questions that did receive answers have been removed from the respective response.

Enhanced Machine Controller Feedback Form

ABSTRACT:

This study of the effects that the EMC program has made on your company will be utilized for a project at Worcester Polytechnic Institute. We are currently researching the EMC program in Small to Medium sized Manufacturers (SME). The results will be integrated in the final effectiveness of EMC.

INSTRUCTIONS:

Below are a few questions that will enable this study to get a better understanding on how EMC has effected the production and effectiveness of your company. Answer the questions with a sentence, or a yes or no. In the remarks section feel free to add any other information that will help this study.

QUESTIONS AND ANSWERS

Question 1.
How has EMC affected the overall production time and rate per piece?

Answers
ZERO

I'm not a job shop, I service and retrofit.

No effect. It works as well as other programs that I have but has many more G codes availble.

Doubled production

Not may uses

In general, the emc has allowed us to perform operations on our non-stock items that we were not doing in-house. Since the operations were being subcontracted, there is no direct before and after rate comparison.

Question 2.
What costs have been reduced from the implementation of EMC?

Answers
The cost of the cnc computer is reduced by about 6k.

None except softwafre costs

I no longer have to buy bug fixes from flakey software vendors.

can now do many more things than before, because of CNC capabilities.

We have been able to keep some of our work in-house, so the cost of subcontracting has been reduced.

Question 3.
Has the EMC program reduced any jobs that were prior needed for the task that EMC is now doing?

Answers
NO

No. In fact I'm thinking of hiring to run emc machines.

No

No- I am a one man operation.

No

Question 4.
With the introduction to EMC would you now upgrade to a more in depth CAM package?

Answers
YES

Don't do much 3D work so programming is okay. I'm working on tcl routines that will make bolt circles and other common patterns easier.

No

I did- I bought Vector CAD/CAM and later bought the 4th axis option

If i got more CNC work, to provide funds.

We have considered upgrading to a commercial CAM package, but decided against it because of the age of the machine and the cost involved. We would consider a commercial CAM package on any new purchases.

Question 5.
How difficult was it for you to find out about and obtain EMC? Would there have been a better way?

Answers
VERY

Got the original hint from rec.crafts.metalworking. Good availability from nist except during the firewall setup.

It was very difficult to find it.

It is easy now
approached by Matt Shaver

EMC came with the machine when we bought it from Matt Shaver. Otherwise we probably would never have heard of EMC.

Question 6.
How difficult was the setup/retrofit of your equipment? Could you think of some better way of doing this?

Answers
Nightmare, Linux is a mess I simply gave up and found something else

A step by step manual with examples would help.

It was difficult on my first machine but have set up ten since then. Now it is easy.

Easy, I have done a few machines now and know what I'm doing. 5 years ago, it was hard for me to get info. Everyone wanted lots of $$$$

Question 7.
What are the best and worst experiences that you've had throughout the whole process of finding and installing EMC?

Answers
ZERO ZERO ZERO O moved to CNCPro it works.

Learning enough about Linux to get started.

Th lack of a library of post processors.

Trying to get a modem to work with Linux to d/l emc was the worse experiemnce. Setting it up for others was the best experience.

Rtlinux installation

Question 8.
What was the cost of the implementation?

Answers
TIME and I can;t afford time..

1500.00

About $500 for hardware.

$39.00 for a Red Hat CD from Comp USA. That's it!!! I had everything else already (including the buggy software from MAXNC- that I threw away)

It was included in the price of the machine when we bought it and was not a separate item.

Question 9.
How long did the overall implementation take?

Answers
Tried for a day and then found it was much to much of a nightmare . Linux never worked. Six months off and on.

On the first unit it took 3 months off and on mainly due to trying to get a modem to work with linux and my inexperience with linux commands.

It took me a couple of weeks to get comfortable with Linux. After
that, I think that it took me several days to get the RTlinux thing set up. EMC was easy enough to install by itself. I converted my CNC over to EMC in 1 day and was making parts for profit that day.

The servo mahine took several months, but the stepper machine was bought with EMC already implemented

Question 10.
What kind of machine/brand/model/controller/motors were converted?

Answers
Homemade mill with steppers. Next is lathe with DC servos.

A mill drill.

Rong Fu mill/drill and mini bed mill

One Ndex milling machine all but the servo equipment and transformers were removed. One Bridgeport empty exept for the motors

Bridgeport Milling machine.

Question 11.
Any further remarks that will help this study appreciate the effectiveness of the EMC program?

Answers
Move to Windows NT2000 and thing will become more real. Linux is the nightmare that will destroy EMC

My guess is that EMC is still experimental and lacks some functions that would make it more attractive.

We are control retrofitters using primarily GE Fanuc controls. I have not implemented any EMC controls. I have been monitoring their progress and have not been too impressed to date with the progress.

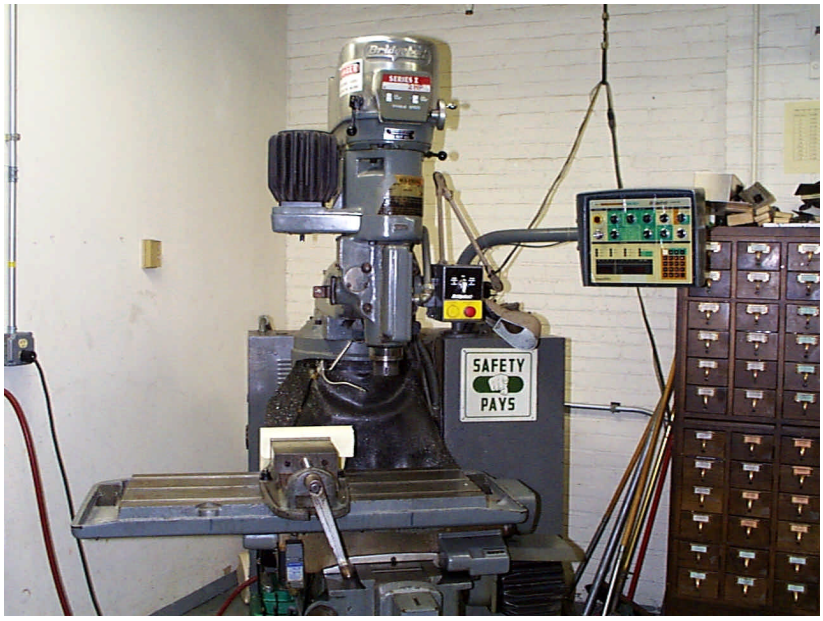
When a autoprobe setup is invoked aI think emc will be a great program.

The best part is that it is always growing and improving and we can all participate in it's developement.

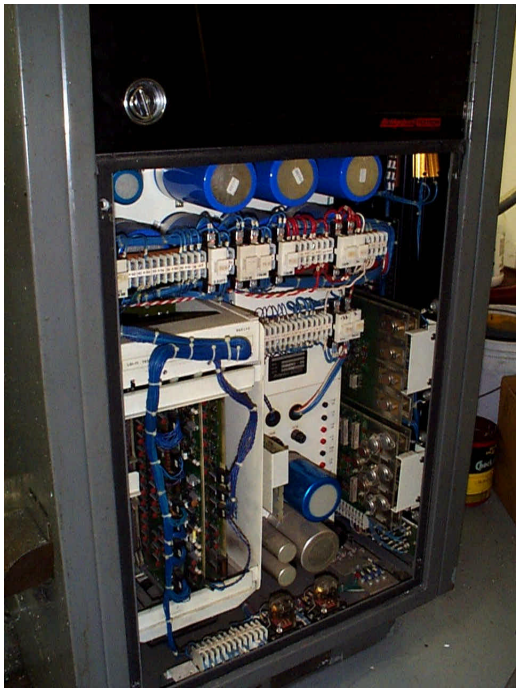
Like it reall easy to use, but tiime condsuming direct hookup for CAD machine to EMC for file transfer would help

Documentation is not a good fit for manufacturing companies. Most of what I've seen is by and for programmers of the machine tool controller software and the technical types that build the machines that use emc. EMC is best suited for hobbyists and those who have time to be constantly tweaking and upgrading the operating system (linux) and the emc software. A production shop requires a more stable system.

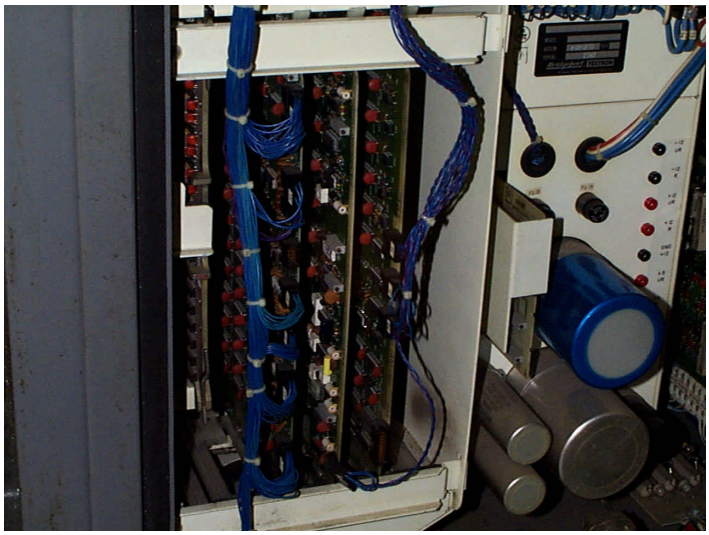
APPENDIX D: PICTURES OF RETROFIT



The Bridgeport that will be retrofit.

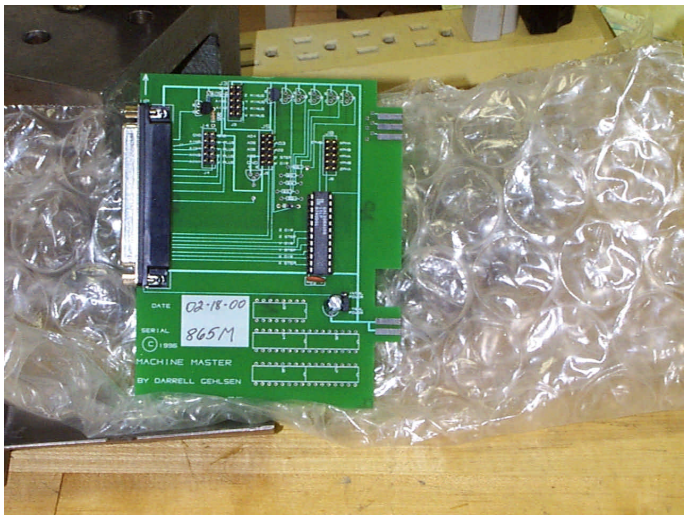


The inside of the BOSS 5 controller cabinet.

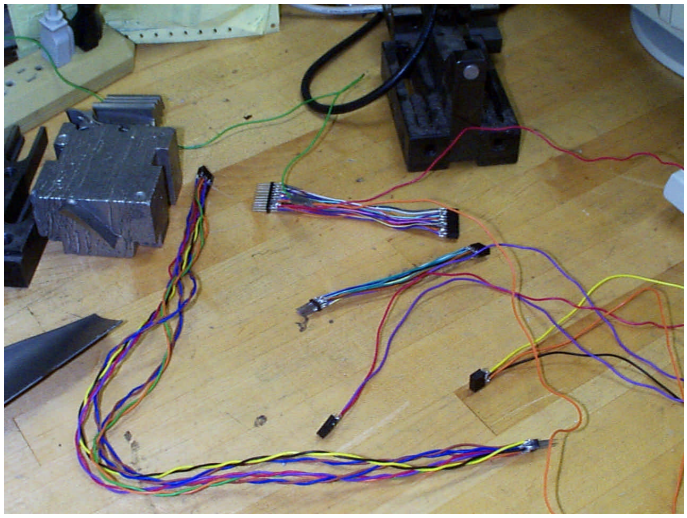


A close up of the card cage.

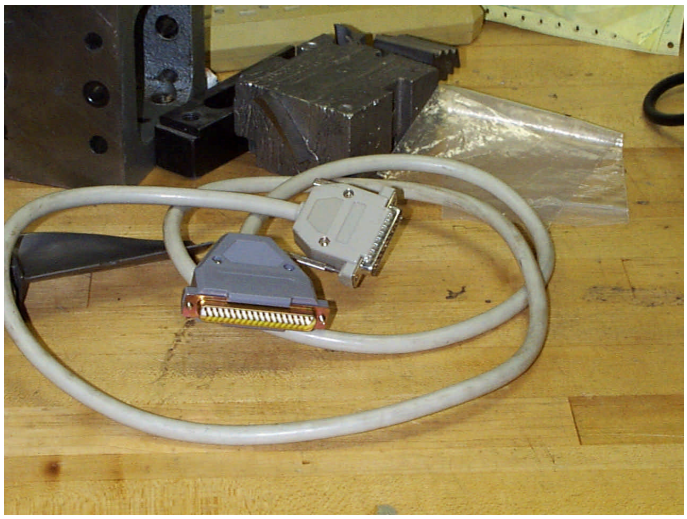
The PC with RTLinux and EMC on it that will control the Bridgeport.



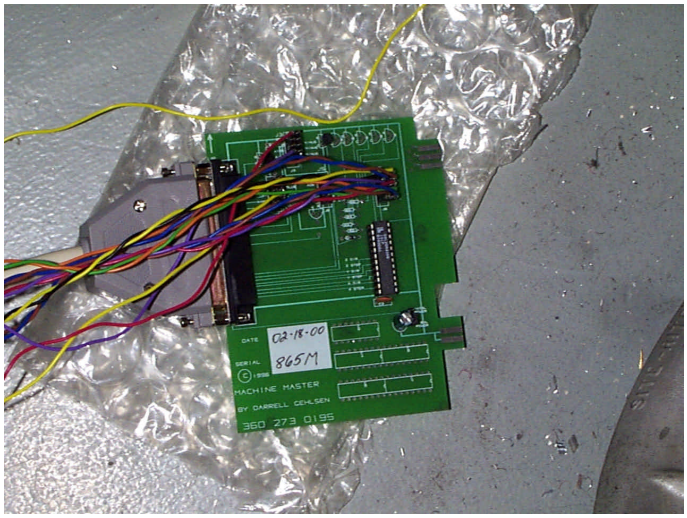
The Servo To Go interface card that will interface the PC and the Bridgeport.



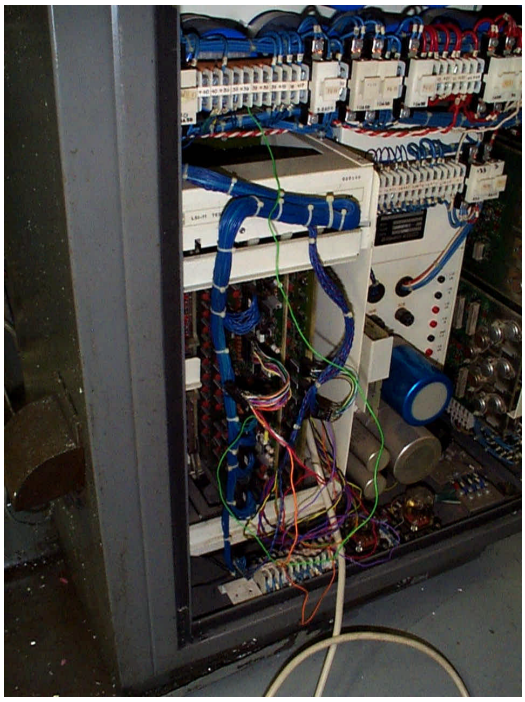
The wiring for the retrofit.



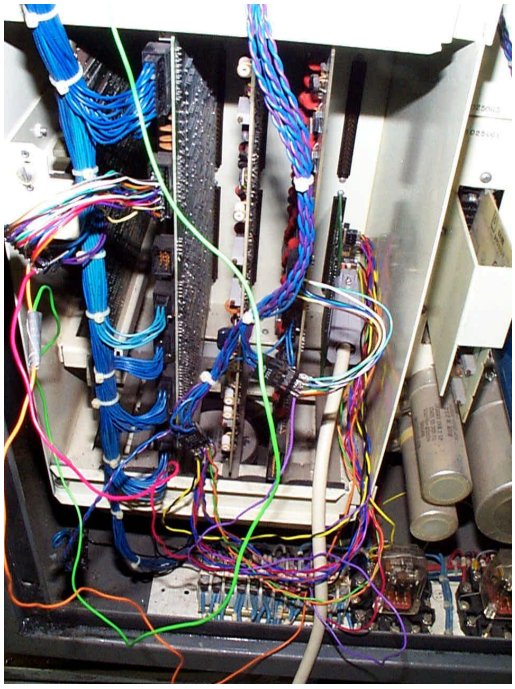
DB-25 to DB-37 interface cable. This connects the PC to the STG card



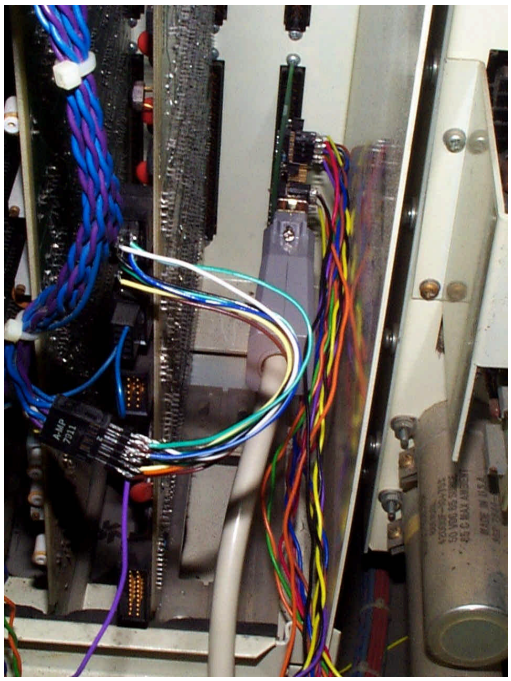
The STG card all wired up.



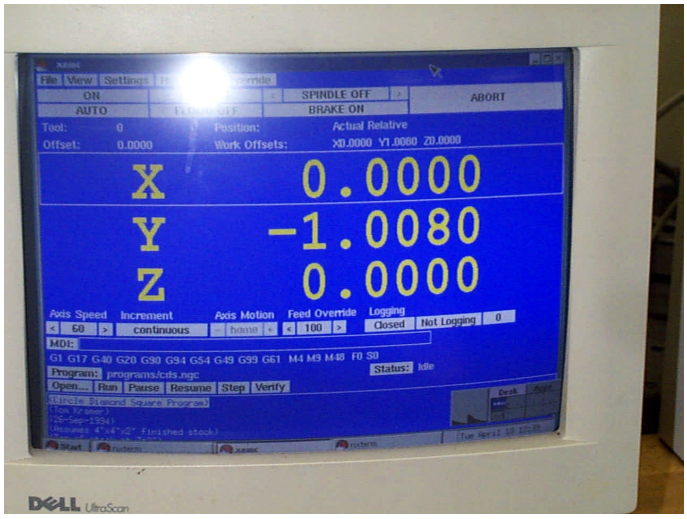
A view of the BOSS 5 cabinet after being wired.



A close up of the wired card cage.



The STG card in the card cage.



A screen shot of EMC running.

Appendix E: Commonly Used G-Codes

G00 positioning (rapid traverse)	G54 work coordinate system 1 select
G01 linear interpolation (feed)	G55 work coordinate system 2 select
G02 circular interpolation CW	G56 work coordinate system 3 select
G03 circular interpolation CCW	G57 work coordinate system 4 select
G04 dwell	G58 work coordinate system 5 select
G07 imaginary axis designation	G59 work coordinate system 6 select
G09 exact stop check	G60 single direction positioning
G10 offset value setting	G61 exact stop check mode
G17 XY plane selection	G64 cutting mode
G18 ZX plane selection	G65 custom macro simple call
G19 YZ plane selection	G66 custom macro modal call
G20 input in inch	G67 custom macro modal call cancel
G21 input in mm	G68 coordinate system rotation ON
G22 stored stroke limit ON	G69 coordinate system rotation OFF
G23 stored stroke limit OFF	G73 peck drilling cycle
G27 reference point return check	G74 counter tapping cycle
G28 return to reference point	G76 fine boring
G29 return from reference point	G80 canned cycle cancel
G30 return to 2nd, 3rd & 4th ref. point	G81 drilling cycle, spot boring
G31 skip cutting	G82 drilling cycle, counter boring
G33 thread cutting	G83 peck drilling cycle
G40 cutter compensation cancel	G84 tapping cycle
G41 cutter compensation left	G85, G86 boring cycle
G42 cutter compensation right	G87 back boring cycle
G43 tool length compensation + direction	G88, G89 boring cycle
G44 tool length compensation - direction	G90 absolute programming
G49 tool length compensation cancel	G91 incremental programming
G45 tool offset increase	G92 programming of absolute zero point
G46 tool offset decrease	G94 per minute feed
G47 tool offset double increase	G95 per revolution feed
G48 tool offset double decrease	G96 constant surface speed control
G50 scaling OFF	G97 constant surface speed control cancel
G51 scaling ON	G98 return to initial point in canned cycle
G52 local coordinate system setting	G99 return to R point in canned cycle

Commonly Used M-Codes	
M00 program stop	M21 tool magazine right
M01 optional stop	M22 tool magazine left
M02 end of program (no rewind)	M23 tool magazine up
M03 spindle CW	M24 tool magazine down
M04 spindle CCW	M25 tool clamp
M05 spindle stop	M26 tool unclamp
M06 tool change	M27 clutch neutral ON
M07 mist coolant ON	M28 clutch neutral OFF
M08 flood coolant ON	M30 end program (rewind stop)
M09 spindle orientation ON	M98 call sub-program
M19 spindle orientation ON	M99 end sub-program

APPENDIX F: LIST OF SMES IN MASSACHUSETTS

HarrisID	CoName	HQStatus	MailAdd	MailCity	Phone
8180402	Doncasters	HQ	PO Box 1970	Springfield	413-732-1122
8181852	Erwin Junker Machinery Inc		11 Veterans Dr	Chicopee	413-739-9969
8182053	Delta Molding Co		PO Box 416	Leominster	978-537-8343
8182609	Rozumek Products		57 Mill St	Middleton	978-777-3089
8182603	Atlantic Machine & Welding Co		6 Necco Ct	Boston	617-426-7940
8231472	Horizontal Machine Co		PO Box 473	Agawam	413-789-2444
8231497	Chiasson, Ron & Son Inc		14 Bardwell St	Belchertown	413-323-5503
8231500	Accurate Machine & Tool Co		32 Dulong Cir	Chicopee	413-593-5550
8231503	J P Precision Machine Co		165 Front St	Chicopee	413-592-8191
8231520	Easthampton Machine & Tool Inc		40 Maine Ave	Easthampton	413-527-8770
8231522	Parkway Machining Inc		14 Industrial Pkwy	Easthampton	413-529-9597
8231531	Quality Tool Inc		PO Box 737	East Longmeadow	413-525-1737
8231536	A & D Machine Service		582 S Westfield St	Feeding Hills	413-789-0407
8231540	Farr's Auto Supply Inc		52 W State St	Granby	413-467-3223
8231565	Qual-Tech Manufacturing Inc		726 Main St	Holyoke	413-552-3428
8231575	D T S		PO Box 7	Holyoke	413-534-8833
8231579	D & B Tool		PO Box 57	Ludlow	413-589-9529
8231580	Express Dies Inc		60 Ravenwood Dr	Ludlow	413-589-1618
8231582	Big John Manufacturing		PO Box 115	Ludlow	413-583-6658
8231583	Lee Tool Co Inc		PO Box 509	Ludlow	413-583-8750
8231584	Ludlow Cutter Grinding Co		PO Box 223	Ludlow	413-543-5037
8231585	Ludlow Tool Co		370 Fuller St	Ludlow	413-583-4819
8231594	Florence Precision		PO Box 94	Leeds	413-586-6611
8231606	Silverbrook Manufacturing Co		13 2nd St	Palmer	413-289-1817
8231645	Marcil Precision		PO Box 905	W Springfield	413-731-7449
8231652	Parts Tool & Die Inc		PO Box 503	W Springfield	413-821-9718
8231653	R & S EDM		PO Box 943	W Springfield	413-746-5091
8231657	Taffy Precision Inc		94 Doty Cir	W Springfield	413-747-8094
8231659	Vin-Built Services		21 Summer St	W Springfield	413-736-2555
8231682	EMCO Tool & Gauge Corp		357 Cottage St	Springfield	413-732-1155
8231684	J & S Machine		90 Memorial Dr	Springfield	413-732-1220
8231685	Precision EDM Inc		90 Memorial Dr	Springfield	413-733-2813
8231699	Bill'T Well Manufacturing		261 Garden St	Feeding Hills	413-789-7335
8231712	R R E N Manufacturing & Engrg		PO Box 425	Ludlow	413-543-4416
8231714	Commercial Machine		34 Front St	Indian Orchard	413-543-8827
8231715	J & F Machine Co		PO Box 51104	Indian Orchard	413-543-4005
8231717	R W Tool Co		PO Box 51376	Indian Orchard	413-543-5523
8231718	Walker Machine Co		PO Box 51103	Indian Orchard	413-543-7923
8231719	Lakewood Mold Co Inc		35 Downing Industrial Pkwy	Pittsfield	413-442-3002
8231726	Suprite Machine Co		48 Potter Mountain Rd	Pittsfield	413-443-3011
8231731	Production Plus Manufacturing		PO Box 1818	Pittsfield	413-442-2447
8231742	Bell, R M Engineering Inc		966 Middlefield Rd	Hinsdale	413-655-2405
8231756	Yankee Mold & Manufacturing		PO Box 261	North Adams	413-664-8182
8231782	Mass Tech Mold		667 Westminster St # B	Fitchburg	978-348-2111
8231795	G & W Precision Inc		PO Box 203	Whately	413-665-0983
8231798	Sand Machine Works		31 Long Plain Rd	South Deerfield	413-665-4370
8231802	Sunderland Manufacturing		38 Bullard Pasture Rd	Wendell	978-544-7612

8231812	Comtech Inc	PO Box 207	Fitchburg	978-345-3030
8231836	Competitor Products	PO Box 306	Gardner	978-632-4821
8231848	Harvard Products Inc	PO Box 338	Harvard	978-772-0309
8231853	Sterling Machine & Mold	PO Box 8	Hubbardston	978-928-5951
8231868	Leominster Micro Welding	51 Howard St	Leominster	978-534-0697
8231888	P & L Machine Co Inc	168 Ayer Rd	Littleton	978-486-9626
8231893	AMTEC	33 Lomar Park	Pepperell	978-433-0505
8231901	Specialized Machine Inc	PO Box 1318	Shirley	978-425-4601
8231905	Patriots Performance Center	881 Patriots Rd	Templeton	978-939-4280
8231915	Pro-Die-Namics Inc	15 Hale St # A	Winchendon	978-297-9882
8231916	Ran Engineering Corp	PO Box 276	Winchendon	978-297-3051
8231933	Gates, Ken Machine	67 Webber Rd	Brookfield	508-867-6933
8231949	North American Tool & Machine	110 North St	East Brookfield	508-867-5154
8231959	B L Tool Inc	158 Sturbridge Rd	Holland	413-245-6560
8231961	S M P Machine	RR 3 Box 135	Holland	413-245-9871
8231972	Nason Machine Co	PO Box 404	Millbury	508-865-3545
8231999	Wear-Rite Corp	PO Box 623	Oxford	508-987-0361
8232004	A M J Fabricating Inc	560 Boston Tpke # 23	Shrewsbury	508-845-1739
8232006	B & K Precision Co	560 Boston Tpke	Shrewsbury	508-845-1696
8232014	A B C Tool	9 Holland Rd	Fiskdale	508-347-3166
8232097	Saeilo Manufacturing	184 Prescott St	Worcester	508-799-9809
8232116	E V L Tool Co	95 Grand St	Worcester	508-795-1950
8232131	Framingham Frame Manufacturing	1 Watson Pl	Framingham	508-788-1090
8232148	J & P Machine Inc	PO Box 592	Framingham	508-620-6467
8232182	Waiteco Machine Inc	4 High St	Acton	978-266-2630
8232255	Patten Machine Co	299 Central St	Hudson	978-562-9847
8232257	Roehr Tool Corp	14 South St	Hudson	978-562-4488
8232264	G L Auto Engineering	109 Mechanic St	Marlborough	508-460-9522
8232275	Summit Tool & Machine Co Inc	61 Summit Ave	Marlborough	508-624-0711
8232297	Birchlers Automotive	4 Mechanic St	Natick	508-653-2845
8232312	Aselbekian Machine	137 Woodland Rd	Southborough	508-480-0854
8232363	T & S Industrial Machining	17 Cranes Ct	Woburn	781-933-1151
8232375	Accuspec Machine Inc	34 Sullivan Rd # 5	North Billerica	978-667-0169
8232381	Beard Machine	PO Box 814	Burlington	781-272-4636
8232382	Machine Shop	PO Box 1126	Burlington	781-270-5221
8232404	Design Engineering Associates	24 Doe Dr	Billerica	978-663-2312
8232410	Productive Concepts Inc	4 Suburban Park Dr	Billerica	978-670-5700
8232427	Simfer Precision Machine	200 Turnpike Rd	Chelmsford	978-256-1105
8232454	Edwards, T J Co	33 Dover St	Brockton	508-583-9300
8232459	Classic Machine	32 Rochambault St	Haverhill	978-521-8887
8232468	P R M Machine	28 Woodland Rd	Georgetown	978-352-5557
8232474	Adom Engineering Co Inc	11 Rogers Rd	Haverhill	978-372-7757
8232475	Baril Steel Rule Die Co	50 Ward Hill Ave	Haverhill	978-373-7910
8232476	Conti Machine Tool Co Inc	38 Middlesex St	Haverhill	978-373-2330
8232492	F & G Machine	147 Marston St	Lawrence	978-725-9363
8232497	Arcade Manufacturing Inc	1 Power St	Lawrence	978-681-7728
8232498	Helfrich Brothers Boiler Works	39 Merrimack St	Lawrence	978-683-7244
8232522	East Coast Metal Works Co Inc	1980 Turnpike St	North Andover	978-975-0077
8232527	CAM Engineering Inc	26 Wellman St	Lowell	978-459-2213
8232551	Merrimac Tool Co Inc	3 Liberty St	Merrimac	978-346-4442

8232560	Palace Manufacturing Corp	25 Sullivan Rd	North Billerica	978-663-6100
8232562	W J S Machine Co Inc	23 Republic Rd	North Billerica	978-663-6646
8232568	Suburban Machine Inc	55 Middlesex St	N Chelmsford	978-251-7488
8232594	R F M Machine Co	265 Pawtucket Blvd	Tyngsboro	978-452-9130
8232600	Stannous Technologies Corp	65 New Salem St	Wakefield	781-246-1119
8232628	Rodco Engineering	PO Box 508	Tewksbury	978-657-8999
8232648	Aero Industrial Machine	286 Washington St	Lynn	781-598-3113
8232676	Applied Machine Technology Inc	23 Noel St	Amesbury	978-388-9152
8232677	Black Bear Machine Inc	PO Box 1002	Amesbury	978-388-5222
8232679	Chase Engineering	23 Noel St	Amesbury	978-388-1677
8232686	Accutech Engineering	250 North St # A6	Danvers	978-750-0766
8232688	Apogee Machining Services	100 Cummings Ctr	Beverly	978-921-5459
8232691	Contemporary Machine Co Inc	416 Cabot St	Beverly	978-921-9173
8232692	D R A Machining	123 Park St	Beverly	978-927-4675
8232697	B & D Tooling	200 Cummings Ctr # 117C	Beverly	978-922-2136
8232705	Roberts Machine Shop	PO Box 673	Beverly	978-927-6111
8232708	Ultra Quality Technology	200 Cummings Ctr	Beverly	978-922-8224
8232714	G T Machine Inc	167 Georgetown Rd	Boxford	978-887-6687
8232722	Jay's Machine Co	10 Birch Rd	Middleton	978-774-0086
8232732	Quick Manufacturing	10 Rainbow Ter # G	Danvers	978-750-4202
8232737	Titus Engineering Inc	250 North St	Danvers	978-777-4079
8232748	T Q M Machine	PO Box 528	Essex	978-768-6362
8232754	Bybon Precision Concepts	298 Essex Ave	Gloucester	978-282-7803
8232757	J & L Welding & Machine Inc	19 Arthur St	Gloucester	978-283-3388
8232761	Sandy Bay Machine	35 Whittemore St	Gloucester	978-282-1524
8232767	Center Manufacturing Corp	17 Hayward St	Ipswich	978-356-8420
8232770	D & S Machining Inc	PO Box 593	Ipswich	978-356-9335
8232774	K C Precision Machining	PO Box 191	Ipswich	978-356-8900
8232805	Marshall Engineering	PO Box 842	Middleton	978-777-7255
8232811	L K M Industries	10 Mulliken Way	Newburyport	978-462-6044
8232812	Markeaton Engineering	5 Perry Way # 1	Newburyport	978-463-8809
8232837	Laser Process Manufacturing	2 Centennial Dr	Peabody	978-531-6003
8232846	Signet Tool & Engineering Inc	205 Newbury St	Peabody	978-535-1788
8232847	S S T Y L E Grinding	58 Pulaski St	Peabody	978-977-9061
8232858	Maker Tool	294 Main St	Rowley	978-948-2464
8232894	Andrill Machine	105 Chapman St	Canton	781-575-9711
8232926	A & M Machine	14 Perry Dr	Foxboro	508-543-0358
8232984	Lucas Manufacturing Co Inc	PO Box 95	Millis	508-533-2010
8232985	Pinky's Truck & Auto Service	1475 Main St	Millis	508-376-0825
8233243	Malden Machine	795 Eastern Ave	Malden	781-322-3246
8233267	Boston Machine Shop	1087 Broadway	Revere	781-485-0600
8233327	Advanced Technology Innovation	20 Slanders Rd # A	Belmont	617-489-7730
8233378	Bomas Machine Specialists Inc	334 Washington St	Somerville	617-628-3831
8233428	J C Tool & Die Inc	101 Tileston St	Everett	617-389-7100
8233443	Nanco	PO Box 6477	Chelsea	617-884-1700
8233460	Automatic Engineering	203 Riverview Ave	Waltham	781-893-6145
8233461	Boynton Machine Co Inc	101 Clematis Ave # 6	Waltham	781-899-9900
8233494	Pelga Engineering	312 Main St	Hudson	978-562-1555
8233534	High Tech Turning Co Inc	16 Bridge St	Watertown	617-926-3505
8233558	Newtron Inc	PO Box 66027	Auburndale	617-969-1100

8233703	Alco Machine Corp		101A French Ave	Braintree	781-848-5657
8233783	M J Machine Inc		1 1st St # 9	Bridgewater	508-697-5329
8233784	Morrison Precision Machine Co		28 Perkins St	Bridgewater	508-697-2541
8233800	Menton Machine Co		PO Box 48	Easton	508-238-1554
8233808	Plymouth Precision Products		353 Circuit St	Hanover	781-826-3342
8233814	Intl Grinding Co		PO Box 728	Hanson	781-294-7228
8233817	Elite Tool & Die Inc		223 Centre St	Holbrook	781-767-9482
8233856	S & S Machine Co Inc		205 Oak St	Pembroke	781-829-8982
8233891	Arbo Machine Co Inc		45 Union St	Rockland	781-871-3449
8233926	Galvin & Jones Machine & Fab		PO Box 173	W Bridgewater	508-584-6282
8233933	A & C Metal Products Inc		PO Box 568	Whitman	781-447-5177
8233940	Eastern Arc & Machine		PO Box 988	Brockton	508-559-6288
8233946	Medeiros Manufacturing Co Ltd		25 Washburn Ave	Brockton	508-584-9202
8233985	Pocasset Machine Inc		PO Box 3088	Pocasset	508-563-5572
8234009	Cotuit Machine & Manufacturing	HQ	2 Hinckley Rd	Hyannis	508-778-2588
8234042	Bigwood Associates Co		74 Lovells Ln	Marstons Mills	508-428-7971
8234079	Howland Tool & Machine Ltd		PO Box 469	Assonet	508-644-5093
8234092	Estrella Tool & Die Co Inc		PO Box 1011	Attleboro	508-222-5698
8234095	Jade Machine & Engineering		44 Forest St	Attleboro	508-223-4500
8234110	Top Line Machine		PO Box 185	North Dighton	508-669-6878
8234171	Bayside Machining Service		PO Box 1179	Mattapoisett	508-758-9221
8234207	Ziegler, A F Co		35 Hawthorne St	North Attleboro	508-699-0620
8234251	Designer Tool Co		49 Industrial Ct	Seekonk	508-336-6433
8234255	K L S Plastic Engineering		36 Maple Ave	Seekonk	508-761-5888
8234259	Q C I Inc		257 Pine St	Seekonk	508-399-8983
8234260	Accu-Laser		PO Box 62	Swansea	508-674-0294
8234266	True Machine Co		2222 G A R Hwy	Swansea	508-336-4474
8234272	Goulart Corp		PO Box 3020	Taunton	508-821-3702
8234276	Reliable Welding		PO Box 2255	Taunton	508-824-5732
8234279	Todrin Laser Industries		600 Somerset Ave	Taunton	508-880-2525
8242055	Hayon Manufacturing		59 Fountain St	Framingham	508-877-8710
8242383	Phoenix Precision Machine		17 Jan Sebastian Dr # 15	Sandwich	508-888-8060
6877112	Healthstar Inc		PO Box 2210	Quincy	617-770-2524
6876916	Southbridge Tool/Manufacturing		181 Southbridge Rd	Dudley	508-764-2779
6876924	Pittsfield Plastics Engrg Inc		PO Box 1246	Pittsfield	413-442-0067
6071294	R D C Machine & Die Co		PO Box 462	Ashburnham	978-827-4793
6071534	D & S Manufacturing Co		PO Box 142	Auburn	508-799-7812
6072656	Nexus Machine & Gallery		20 Rawson St	Dorchester	617-436-3899
6078042	Toolmex Corp	HQ	1075 Worcester Rd	Natick	508-653-8897
6080170	Rawling Gear Inc		890 Hartford Tpke	Shrewsbury	508-845-2141
6081624	Van Keuren		45 Loring Dr	Framingham	508-872-1450
6330799	Connell LP	HQ	1 International Pl	Boston	617-737-2700
8072678	Package Machinery Co		380 Union St	W Springfield	413-732-4000
8089786	Barnard Die Inc		247B Water St	Wakefield	781-245-0573
8089789	Adaptive Engineering Inc		55 Pond St	Waltham	781-894-7371
8089792	Worcester Gear Works Inc		PO Box 15026	Worcester	508-755-3109
8089797	Intermagnetics General Corp		300 Vesper Executive Park # E	Tyngsboro	978-649-8590
8089802	Standard Chain Co		PO Box 66	North Attleboro	508-695-6611
8089828	Trivak Co		280 Howard St	Lowell	978-453-7123
8089841	Brockton Tool Co		7 Central St	South Easton	508-238-2062

8089855	United Die Corp	PO Box 6004	Danvers	978-777-0800
8089859	Bass Precision Products	PO Box 3204	Beverly	978-921-1160
8089881	Honematic Machine Corp	PO Box 1100	Boylston	508-869-2131
8089929	Form Roll Die Corp	217 Stafford St	Worcester	508-755-2010
8089949	Isolation Technologies Inc	4 Business Way	Hopedale	508-478-0111
8089952	Bermer Tool & Die Inc	PO Box 159	Southbridge	508-764-2521
8089985	Hardy, L Co	PO Box 267	Worcester	508-756-1511
8089995	Apex Engineering Inc	17 Downing Industrial Pkwy	Pittsfield	413-442-1414
8090011	Centrall Centerless Grinding	192 Central St	Saugus	781-233-5229
8090038	Jordan Engineering Co Inc	585 Manley St	W Bridgewater	508-580-1270
8090076	Belanger Brothers Industrial	PO Box 505600	Chelsea	617-884-1308
8090108	Pan Tec Inc	12 Republic Rd	North Billerica	978-663-5130
8090124	Mc Carthy Steel Rule Cutting	44 Allston Ave	W Springfield	413-739-8115
8090127	Market Grinding Inc	PO Box 3117	Woburn	781-938-4292
8090132	C R Machine Co	13 Alexander Rd	Billerica	978-663-3989
8090156	Moldcraft Co Inc	PO Box 490	Westfield	413-568-0461
8090171	United Tool & Die Co Inc	98 Eames St	Wilmington	978-658-5500
8090177	Banner Mold & Die Co Inc	251 Florence St	Leominster	978-534-6558
8090198	Peterson & Nash Inc	PO Box 1238	West Hanover	781-826-9085
8090199	Valley Design Corp	63 Power Rd	Westford	978-692-1971
8090208	Morton & Co Inc	11 Eames St	Wilmington	978-657-7726
8090216	Moore Manufacturing Co Inc	6 Garden St	Danvers	978-777-2080
8090224	Rol Laboratory Research/Dvlpt	223 Crescent St	Waltham	781-891-8615
8090246	M & K Engineering Inc	66 Concord St	North Reading	978-276-1973
8090250	Control Technology Corp	25 South St # E	Hopkinton	508-435-9595
8090253	Almarc Machine Co	13 Felton St	Waltham	781-647-0014
8090271	Dual Manufacturing/Engineering	Bigelow St	Holyoke	413-536-4940
8090289	General Iron & Steel Works Inc	600 Essex St # B	Lawrence	978-686-9518
8090302	Richards Micro-Tool Inc	250 Nicks Rock Rd	Plymouth	508-746-6900
8090327	Plainville Machine Works Inc	PO Box 1508	Plainville	508-699-7575
8090343	Geonautics Manufacturing Inc	PO Box 230	Newburyport	978-462-7161
8090355	North Attleboro Taps Inc	PO Box 487	North Attleboro	508-699-7581
8090398	Seekonk Manufacturing Co Inc	87 Perrin Ave	Seekonk	508-761-8284
8090411	Atron Machine	PO Box 1618	Waltham	781-894-0843
8090415	Dynamic Machine Works Inc	12 Suburban Park Dr	Billerica	978-667-0202
8090442	Leominster Tool Co Inc	PO Box 478	Leominster	978-534-6501
8090456	Carvers' Guild	PO Box 198	West Groton	978-448-3063
8090480	S P M Corp	73 Holton St	Woburn	781-721-5450
8090531	D & S Manufacturing Co	PO Box 1133	Southwick	413-569-5688
8090542	Matheson Higgins Congress	166 New Boston St	Woburn	781-935-6400
8090551	Holden Plastics Corp	PO Box 25	Worcester	508-756-6241
8090553	Professional Tool Grinding Co	18 Plymouth Dr	South Easton	508-230-3535
8090556	AccuRounds Inc	15 Doherty Ave	Avon	508-587-3500
8090572	Accudynamics Inc	395 Plymouth St	Middleboro	508-946-4545
8090596	Phoenix Metallurgical Inc	PO Box 12	Hopedale	508-473-8815
8090629	Montague Machine/Kenco Metals	PO Box 777	Turners Falls	413-863-4301
8090634	Basque Plastics Corp	28 Jytek Dr	Leominster	978-537-5219
8090635	Vogform Tool & Die Inc	56 Doty Cir	W Springfield	413-737-6947
8090650	Thermo-Craft Engineering Corp	701 Western Ave	Lynn	781-599-4023
8090659	Manchester Precision Products	39 Union St	Manchester	978-526-4127

8090663	Esco Tool Co	PO Box 530	Medfield	508-359-4311
8090665	Allied Manufacturing Co Inc	50 Millbrook St	Worcester	508-755-6154
8090670	Jet Products Inc	221 Highland St	E Bridgewater	508-378-3200
8090672	Thorsen/Compufab Inc	244 Bodwell St	Avon	508-588-3400
8090681	Lentros Engineering Inc	179 Main St # A	Ashland	508-881-1160
8090690	Assonet Industries Inc	PO Box 408	Assonet	508-644-5001
8090692	Muise Machine Shop	131 Lexington St	Waltham	781-899-1901
8090713	Acorn Manufacturing Inc	PO Box 31	Mansfield	508-339-4500
8090793	Accuspec	19 Manns Ct	Woburn	781-933-4942
8090800	Neuber Industrial Diamond Co	10 B St	Burlington	781-273-5656
8090821	New England Mold Sterling Inc	50 Pratts Junction Rd	Sterling	978-422-8656
8090869	Northeast Manufacturing Co Inc	35 Spencer St	Stoneham	781-438-3022
8090917	J J T Engineering Inc	PO Box 51	Wilmington	978-657-4137
8090921	Compumachine Inc	645 Main St	Wilmington	978-657-8440
8090924	Churchill Corp	PO Box G	Melrose	781-665-4700
8090933	Tool Technology	121 Liberty St	Danvers	978-777-5006
8090937	Allen, Charles G Co	PO Box 399	Barre	978-355-2911
8090948	J B Machine Co	PO Box 1151	Southwick	413-789-7582
8090986	Atlas Die Inc	PO Box 620	Palmer	413-289-1276
8091023	Burr Industries Inc	495 Newbury St	Danvers	978-774-2527
8091034	Adams, John J Corp	PO Box 157	Worcester	508-757-3894
8091085	E T M Manufacturing Co	21 Concord St	Wilmington	978-658-2485
8091091	Union Gear & Sprocket Corp	PO Box 9161	Quincy	617-479-6800
8091111	Prattville Machine & Tool Co	147 Beech St	Chelsea	617-889-2419
8091114	Bruce Diamond Corp	PO Box 420	Attleboro	508-222-3755
8091119	Vulcan Co Inc	PO Box 36	Hingham	781-337-5970
8091165	North East Surgical Tool Co	35 Corporate Park Dr	Pembroke	781-826-6266
8091177	Boston Precision Parts Co Inc	46 Sprague St	Hyde Park	617-361-1000
8091208	Evans Industries Inc	PO Box 169	Topsfield	978-887-8561
8091209	M & H Engineering Co	183 Newbury St	Danvers	978-777-1222
8091224	B-C-D Metal Products Inc	PO Box 556	Everett	617-389-0342
8091251	Cliflex Bellows Corp	PO Box E 61	Boston	617-268-5774
8091294	Stan-Allen Co Inc	Po Box 543	Ludlow	413-589-9961
8091322	Lincoln Tool & Machine Corp	PO Box 66	Marlborough	508-485-2940
8091350	S W Keats Co	10 Green St	Woburn	781-935-4282
8091356	Standley Brothers Machine Co	PO Box 85	Beverly	978-927-0278
8091372	Knight, George & Co Inc	PO Box 766	Brockton	508-588-0186
8091380	Brockton Boston Cutting Die	1876 Memorial Dr	Avon	508-583-3650
8091397	Boniface Tool & Die Inc	PO Box 249	Southbridge	508-764-3248
8091418	H & H Machine Co	20 W Water St	Taunton	508-823-1745
8091420	Lapointe Hudson Broach Corp	569 Main St	Hudson	978-562-7943
8091429	Hutchins Tool & Engineering	60 Brookdale Rd	Springfield	413-781-6280
8091454	De Cha Inc	200 Willard St	Quincy	617-773-9600
8091469	Wrentham Steel Products Co	PO Box 357	Wrentham	508-384-2166
8091503	H & S Machine Co Inc	PO Box 897	Lawrence	978-686-2321
8091582	Lavelle Machine & Tool Co Inc	PO Box 1558	Westford	978-692-8825
8091640	A & A Industries Inc	320 Jubilee Dr	Peabody	978-977-9660
8091647	R & F Micro Tool Co	PO Box 310	Pembroke	781-826-6386
8091660	Beverly Pattern Inc	PO Box 118	Beverly	978-927-0052
8091662	Niagara Cutter-Athol Inc	273 Main St	Athol	978-249-2788

8091667	Centerville Manufacturing		PO Box 745	Centerville	508-790-0993
8091678	Honorcraft Inc		292 Page St # A	Stoughton	781-341-0410
8091680	Intech Inc		979 Main St	Acton	978-263-2210
8091703	Mark Tech Inc		113 Tolman Ave	Leominster	978-537-8051
8091732	Revere Sink Corp		12 Coffin Ave	New Bedford	508-997-1266
8091734	Armac Industries Co Inc		925 Airport Rd	Fall River	508-676-3051
8091776	Alexander Machine & Tool Co		49 High St	Woburn	781-935-0010
8091802	United County Industries Corp	HQ	PO Box 320	Millbury	508-865-3552
8091816	Atlantic Valve Corp		PO Box 774	Westfield	413-568-3366
8091831	Walker Pattern & Mold Inc		PO Box 416	Auburn	508-754-9630
8091871	Jones Machine Co Inc		4 Canal St	Danvers	978-774-1140
8091909	Boulevard Machine & Gear Inc		785 Page Blvd	Springfield	413-788-6466
8091922	Howes Engineering & Machining		25 Kenwood Cir	Franklin	508-528-6500
8091941	Johnson Foils Inc		40 Progress Ave	Springfield	413-733-6603
8091949	Knowlton Industries Inc		43 Prince St	Danvers	978-777-6091
8091952	Everett Pattern/Manufacturing		194 S Main St	Middleton	978-777-4575
8091963	Wells Tool Co		PO Box 231	Greenfield	413-773-3465
8091973	Parker Machine LLC		510 State Rd	North Adams	413-664-6121
8091991	Auciello Iron Works Inc		PO Box 424	Hudson	978-568-8382
8092003	Apahouser Inc		413 River Rd	Hudson	978-567-9800
8092008	Rock Valley Tool Inc		54 Oneil St	Easthampton	413-527-2350
8092044	Springfield Mold Works Inc		184 Falcon Dr	Westfield	413-568-0322
8092045	Techni-Products Inc		PO Box 215	East Longmeadow	413-525-6321
8092067	Kentron Machine Co Inc		624 South St	Holbrook	781-767-9888
8092076	Service Machine Inc		PO Box 950	Holyoke	413-538-9535
8092085	Atlas Metal Products Co Inc		312 Main St	Hudson	978-568-8343
8092089	Fisher, Carl Co Inc		PO Box 2209	Springfield	413-736-3661
8092094	Clay Group Inc		28 Bowditch Dr	Worcester	508-852-2233
8092122	Ty-Wood Corp		PO Box 6710	Holliston	508-429-4011
8092137	Thermoplastics Co Inc		24 Woodward St	Worcester	508-754-4668
8092148	Dexter Magnetic Materials		700 Technology Park Dr	Billerica	978-663-7500
8092205	Barker Steel		PO Box 122	South Deerfield	413-665-3752
8092231	Precision Machinists Inc		299 Littleton Rd	Chelmsford	978-256-4592
8092240	Hollis Industries Inc		PO Box 6227	Holliston	508-429-4328
8092242	Donahue Industries Inc		5 Industrial Dr	Shrewsbury	508-845-6501
8092255	D J M Precision Machining		100 Cummings Ctr # 110C	Beverly	978-922-0407
8092259	Santin Engineering Inc		1 Lakeland Park Dr	Peabody	978-535-5511
8092264	Cindex Industries Inc		42 Perimeter Rd	Ludlow	413-589-9151
8092289	Ikonen Tool & Die Co Inc		PO Box J	Gardner	978-632-2197
8092303	Dumont Corp		PO Box 469	Greenfield	413-773-3674
8092309	S & S Machine & Welding		128 Windsor Rd	Savoy	413-743-7799
8092331	G T G Inc		PO Box 366	Middleton	978-777-5010
8092351	Lemco-Miller Corp		PO Box 334	Danvers	978-774-1233
8092375	Miller, A G Co Inc		53 Batavia St	Springfield	413-732-9297
8092456	Associated Electro Mechanics		PO Box 2650	Springfield	413-781-4276
8092461	Modern Mold & Tool Inc	HQ	1995 East St	Pittsfield	413-443-1192
8092463	Krofta Southern Berkshire Corp		PO Box 684	Lenox	413-637-0639
8092466	Central Mass Machine Inc		PO Box 223	Holyoke	413-538-9880
8092471	Falls Machine Screw Co Inc		680 Meadow St	Chicopee	413-592-7791
8092492	Pen Ro Group		343 Pecks Rd	Pittsfield	413-499-0464

8092497	Yankee Hill Machine Co Inc	20 Ladd Ave	Florence	413-584-1466
8092501	Stenor Tool Co Inc	944 Sheridan St	Chicopee	413-593-1467
8095893	JIT Manufacturing Inc	565 North Rd	Westfield	413-562-3853
8100161	Arrow Precision Inc	PO Box 27	Agawam	413-786-9359
8100163	Bay-Conn Machine	952 Suffield St	Agawam	413-786-2030
8100166	Ben Franklin Design & Mfg	168 Elm St	Agawam	413-786-4220
8100172	J-K Tool Co Inc	41 Russo Cir	Agawam	413-789-0613
8100175	Impala Manufacturing Inc	PO Box 828	Agawam	413-789-2107
8100180	Raymond Industries Inc	PO Box 445	Agawam	413-789-0597
8100186	Wayne Industries Inc	PO Box 246	Agawam	413-786-0252
8100190	Wyz Machine Co Inc	95 Industrial Ln	Agawam	413-786-6816
8100192	M C P M Inc	261 Garden St	Feeding Hills	413-789-4055
8100218	Arrow Machine Co	PO Box 902	Belchertown	413-323-7280
8100230	Beaulieu Tool & Die Co Inc	PO Box 387	Chicopee	413-594-2783
8100231	Delta Machine & Tool Inc	165 Front St	Chicopee	413-594-2118
8100235	Lloyd's Precision Inc	798 Airport Industrial Park Rd	Westfield	413-562-6021
8100238	M G Machine Co	90 Exchange St	Chicopee	413-592-6323
8100242	Phoenix Manufacturing Inc	694 Center St	Chicopee	413-734-4000
8100244	Riverdale Tool & Die Co	945 Meadow St	Chicopee	413-592-0904
8100253	Chicopee Engineering Assocs	PO Box 522	Chicopee	413-592-5321
8100255	Chicopee Welding & Tool Inc	40 Haynes Cir	Chicopee	413-598-8215
8100259	Interdesign Inc	40 Old James St	Chicopee	413-532-7361
8100267	Roger's General Machining	181 Ludlow Rd	Chicopee	413-532-4673
8100270	Innovative Mold & Machine	87 Montcalm St	Chicopee	413-536-4221
8100274	American Specialty Grinding	904 Sheridan St	Chicopee	413-593-5216
8100277	Duval Precision Grinding Inc	940 Sheridan St	Chicopee	413-593-3060
8100278	Forging Tool & Die Co Inc	64 Dulong Cir	Chicopee	413-593-5024
8100286	Easthampton Quality Machine Co	PO Box 829	Easthampton	413-527-1650
8100290	M & R Machine & Tool Co Inc	23 Oneil St	Easthampton	413-527-7000
8100301	Alpha Omega Tool & Die Co	225 Shaker Rd	East Longmeadow	413-525-7292
8100302	Asset Cutting Dies Inc	PO Box 163	East Longmeadow	413-525-1890
8100306	Flag Precision Corp	PO Box 955	East Longmeadow	413-525-7211
8100307	Lombardo Tool & Machine Inc	PO Box 422	East Longmeadow	413-525-6998
8100308	Mill River Tool Co Inc	10 Maple Ct	East Longmeadow	413-525-7241
8100325	S A Machine Co	PO Box 386	Hampden	413-525-2659
8100329	G & L Tool Corp	PO Box 428	Agawam	413-786-2535
8100330	Gosselin Tool Co Inc	PO Box 251	Feeding Hills	413-786-2780
8100332	Norgaard Machine Inc	PO Box 249	Feeding Hills	413-789-1291
8100336	Magnet Wave Products	220 Main St	Gilbertville	413-477-6916
8100337	C & G Machine Co	180 W State St	Granby	413-467-9556
8100362	Emerald Tool Manufacturing	66 Mainline Dr # B	Westfield	413-562-8663
8100364	General Machine Inc	56 Jackson St	Holyoke	413-533-5744
8100376	Koegel's, Charles & Sons Inc	306 Race St	Holyoke	413-532-4752
8100386	Precision Machine Tool	155 N Canal St	Holyoke	413-538-9766
8100391	Riverview Machine Co Inc	102 Cabot St	Holyoke	413-533-5366
8100393	Springdale Machine & Gear Inc	PO Box 829	Holyoke	413-536-2976
8100412	Gatehouse Machine & Weld Inc	PO Box 901	Holyoke	413-532-3591
8100422	A & P Machine Co	1189 East St	Ludlow	413-583-5288
8100423	Aube Precision Tool Inc	54 Moody St	Ludlow	413-589-9048
8100426	Center Machine Co	PO Box 433	Ludlow	413-589-9800

8100427	Custom Machining Industries	824 Perimeter Rd	Ludlow	413-589-7170
8100432	L & L Machine Inc	311 West St	Ludlow	413-583-3110
8100434	Hole Specialists Inc	264 Moody St	Ludlow	413-589-7858
8100444	Worthy Tool & Die Co	23 Oregon Rd	Ludlow	413-583-3431
8100454	Precise Machine Tool Co	PO Box 79	Monson	413-267-3414
8100467	Hebco Tool & Manufacturing Co	67 Hatfield St	Northampton	413-584-6875
8100482	Bay State Machine Co	76 Industrial Park Dr	Northampton	413-584-1631
8100497	Wilderness Mold Inc	17 West St	West Hatfield	413-247-0500
8100498	Basic Precision	PO Box 907	Palmer	413-283-7938
8100504	Hullihen Machine Co	PO Box 1	Palmer	413-283-2383
8100518	J & E Precision Tool Inc	579 Southampton Rd	Westfield	413-572-1788
8100521	Knight Machine & Tool Co	11 Industrial Dr	South Hadley	413-532-2507
8100532	Whip City Tool & Die Corp	PO Box 99	Southwick	413-569-5528
8100536	Harrison Insulation Products	PO Box 30	Ware	413-967-6321
8100537	Mark Machine Co	97 Monson Rd	Wales	413-267-4880
8100540	Cycle Engineering Inc	15 Parker St	Ware	413-967-3818
8100545	Machine Products Inc	PO Box 321	Ware	413-967-3951
8100562	D & D Tool Inc	66 Mainline Dr # C	Westfield	413-568-4455
8100565	Hemco Tool & Die Inc	PO Box 326	Westfield	413-568-7940
8100566	Hy-Tec Enterprises Inc	77 Mill St	Westfield	413-562-6087
8100567	Jason Tool Co	15 Ponders Hollow Rd	Westfield	413-562-6406
8100569	Millrite Machine Co	587 Southampton Rd	Westfield	413-562-9212
8100573	Omni Manufacturing Co	51 Church St	Westfield	413-568-6175
8100575	Peerless Precision Inc	66 Mainline Dr	Westfield	413-562-2359
8100576	Performance Tool Inc	PO Box 1734	Westfield	413-568-6643
8100577	P F R Machine Co	PO Box 1478	Westfield	413-568-7603
8100578	Pond Brook Machining	88 Mainline Dr # B	Westfield	413-562-7411
8100580	Pride Machining Inc	337 N Elm St	Westfield	413-568-9884
8100582	Quality Machining Co Inc	PO Box 164	Westfield	413-562-0389
8100587	Texcel Inc	PO Box 426	East Longmeadow	413-525-5700
8100592	Westfield Tool & Die Inc	PO Box 608	Westfield	413-562-2393
8100596	Whalley Precision Inc	28 Hudson Rd	Southwick	413-569-1400
8100598	Z & M Manufacturing	PO Box 1929	Westfield	413-568-8085
8100600	Creative Plastics Inc	PO Box 1633	Westfield	413-562-3884
8100603	Industrial Cutting Tools Inc	PO Box 548	Westfield	413-562-2996
8100605	Precise Turning	PO Box 428	Westfield	413-562-0052
8100606	K & B Tool Inc	PO Box 37	Westfield	413-568-3571
8100613	Vector Tool & Die	317 Northwest Rd	Westfield	413-562-1616
8100614	Ev-Rite Tool Inc	PO Box 251	Westfield	413-568-1433
8100616	Mass Precision	PO Box 369	Westfield	413-568-5944
8100625	Center Line Industries Inc	170 Norman St	W Springfield	413-739-9354
8100631	Deluxe Diecut Inc	PO Box 268	W Springfield	413-736-3374
8100635	Falcon Machine Co	211 Union St	W Springfield	413-737-5842
8100650	Mutual Precision Inc	100 Doty Cir	W Springfield	413-739-6627
8100651	Nortek Inc	70 Doty Cir	W Springfield	413-781-4777
8100653	Northern Associates	83 Spring St	W Springfield	413-734-1342
8100654	Numeric Inc	195 Wayside Ave	W Springfield	413-732-6544
8100659	Promach Inc	190 New Bridge St	W Springfield	413-737-9355
8100665	T & M Automotive	2296 Westfield St	W Springfield	413-746-0450
8100667	True Precision Inc	17 Allston Ave	W Springfield	413-788-4226

8100671	Wayside Engineering Inc	6 Doty Cir	W Springfield	413-739-6047
8100674	Woodlawn Tool & Gage Co Inc	114 Myron St	W Springfield	413-733-7560
8100679	Micon Steel Rule Die	PO Box 11	W Springfield	413-781-3411
8100681	Sharp Precision Grinding Co	PO Box 852	W Springfield	413-737-8808
8100687	New England Broach Co Inc	PO Box 45	Whately	413-665-7064
8100708	Ideal Engraving Co	391 Dwight St	Springfield	413-732-0283
8100729	General Mold & Tool Inc	12 Cass St	Springfield	413-739-3614
8100730	JADCO Inc	259 Page Blvd	Springfield	413-781-1670
8100739	Robert's Manufacturing Co	160 Progress Ave	Springfield	413-737-2283
8100791	Highland Machine Co Inc	433 Eastern Ave	Springfield	413-732-0945
8100792	Intl Valve	PO Box 2649	Springfield	413-736-3682
8100802	Dyno Machine Inc	248 Laconia St	Springfield	413-543-3250
8100803	K & W Machine Works Co	146 Verge St	Springfield	413-543-3329
8100811	B & R Machine Inc	34 Front St	Indian Orchard	413-543-2120
8100814	Fiore Machine Inc	PO Box 51972	Indian Orchard	413-543-5767
8100816	Johns Precisions	34 Front St	Indian Orchard	413-543-3666
8100821	M R D Design Manufacturing	49 Pinevale St	Indian Orchard	413-543-2012
8100824	R & D Technologies	34 Front St	Indian Orchard	413-543-2822
8100826	G Q Machine Co	1323 Worcester St	Indian Orchard	413-543-8441
8100843	Lander Inc	214 Highland Ave	Pittsfield	413-448-8734
8100846	M R M Machine & Tool Inc	45 Santa Maria Pl	Pittsfield	413-443-3804
8100850	Proto Tech Industries	1389 W Housatonic St	Pittsfield	413-447-8831
8100858	Manu-Tech Industries Inc	17 Taconic Park Dr	Pittsfield	413-447-7794
8100868	Richwell Mold & Tool Inc	27 Hungerford St	Pittsfield	413-448-8100
8100870	Allyn, Stuart Co Inc	17 Taconic Park Dr	Pittsfield	413-443-7306
8100877	Pierce Machine Co	21 Grove St Rear	Adams	413-743-0334
8100879	T & A Tool Inc	73 Summer St	Adams	413-743-5917
8100881	H & R Machine Co Inc	PO Box 6	Adams	413-743-5610
8100884	Washington Mountain Precision	465 Frost Rd	Becket	413-623-5511
8100885	Lansen Mold Co	PO Box 1481	Lanesboro	413-443-5328
8100891	Wahconah Mold & Tool Co Inc	PO Box 297	Dalton	413-684-1467
8100925	Innovative Tooling Co Inc	PO Box 257	Lenox Dale	413-637-1031
8100926	Advanced Machine & Tool Inc	180 Pittsfield Rd	Lenox	413-637-9714
8100930	Deerfield Machine & Tool Inc	PO Box 152	North Adams	413-664-6771
8100943	Tog Machining Co Inc	1454 S State St	North Adams	413-664-6711
8100954	Balgen Machine Co Inc	PO Box 374	W Stockbridge	413-232-4209
8100991	Premium Mold & Tool Inc	667 Westminster St	Fitchburg	978-345-1965
8101009	Tri-State Precision Inc	1 Ashuelot Rd	Northfield	413-498-2961
8101010	Sisson Engineering Corp	330 Old Wendell Rd	Northfield	413-498-2840
8101038	Allied Components Inc	PO Box 2641	Fitchburg	978-345-3010
8101045	Bisson Tool & Die Co	830 Westminster St	Fitchburg	978-343-6443
8101055	F E Inc	PO Box 2513	Fitchburg	978-345-2275
8101059	Harris Tool & Die Co Inc	655 Westminster St	Fitchburg	978-345-2320
8101060	Hebert Tool Co	PO Box 306	Fitchburg	978-342-3887
8101067	Lindgren & Sons Machining Inc	327 Elm St	Fitchburg	978-342-7189
8101093	Twin City Machining Inc	555 Chase Rd	Lunenburg	978-582-0480
8101097	Brenmar Molding Inc	1361 Rindge Rd	Fitchburg	978-343-3198
8101111	Mini-Broach Machine Co Inc	PO Box 129	Ashby	978-386-7959
8101116	Hitec Products Inc	PO Box 790	Ayer	978-772-6963
8101117	Hudson Machine Co	28 Harvard Rd	Ayer	978-772-6377

8101136	Conti Precision Tool	PO Box 885	Gardner	978-632-6224
8101157	Gro-Lex Inc	PO Box 48	Groton	978-448-3316
8101159	Groton Screw Machine Co	37 Gilson Rd	Groton	978-448-2502
8101164	Martin Tool & Manufacturing	PO Box 329	Hubbardston	508-886-6211
8101173	Alsco Precision Machine Co	214 Nashua St	Leominster	978-534-4131
8101177	B F W Tool & Die Co Inc	31 Spruce St	Leominster	978-534-9545
8101186	Chapdelaine Tool Co	256 Spruce St	Leominster	978-537-5998
8101193	Ermini Tool & Die Co	PO Box 222	Leominster	978-534-0865
8101197	F & M Tool & Die Co	62 Lakeview St	Leominster	978-537-0290
8101199	Girouard Tool & Die Inc	218 Viscoloid Ave	Leominster	978-534-4147
8101202	Grove Products Inc	PO Box 240	Leominster	978-534-5188
8101203	G & S Tool & Die Inc	PO Box 307	Leominster	978-534-5533
8101214	Lamanna Precision Inc	56 Marshall St	Leominster	978-840-0361
8101216	Leominster Die Service Inc	45 Francis St	Leominster	978-537-3476
8101223	Le Blanc, Paul Inc	43 Johnson St	Leominster	978-537-9572
8101231	Roger's Auto Machine Shop	1275 Central St	Leominster	978-534-6636
8101232	R & S Machine Inc	58 Monarch St	Leominster	978-537-5528
8101236	Scott's Machine Shop	138 Laurel St	Fitchburg	978-342-5494
8101239	Amburgey, S M Welding/Machine	220 Rindge Tpke	Ashburnham	978-827-4550
8101240	Stan-Cast Inc	215 Hamilton St	Leominster	978-537-8306
8101244	Thermoplastics Engineering	11 Spruce St	Leominster	978-537-8135
8101246	Vertex Tool & Die Inc	190 Central St	Leominster	978-840-6648
8101255	C & C Machine	410 Great Rd	Littleton	978-486-4104
8101262	Moran, Robert J Inc	PO Box 592	Littleton	978-486-4718
8101264	A & C Tool Co	493 West St	Lunenburg	978-342-9890
8101277	Keystone Precision Inc	16 Lomar Park Dr # 3	Pepperell	978-433-8484
8101279	Melanson Welding & Machine Co	16 Lomar Park Dr	Pepperell	978-433-8405
8101286	A P Machine Co	PO Box 335	Templeton	978-939-2152
8101291	North End Machine Co	221 N End Rd	Townsend	978-597-5686
8101348	P & R Machine	708 Rathbun St	Blackstone	508-883-3102
8101356	Allied Metal Products Co	278 Southbridge Rd	Charlton	508-248-7311
8101366	Built-Rite Tool & Die Co	807 Sterling Rd	Lancaster	978-365-9245
8101369	Curtis Tool Co	55 Sterling St	Clinton	978-365-5091
8101370	E J Tool	PO Box 736	Clinton	978-368-7047
8101379	Sonic Research	17 Parker St	Clinton	978-368-1670
8101381	Di-Al Machine Co	PO Box 422	East Brookfield	508-867-2366
8101382	New Tech Inc	153 Adams Rd	East Brookfield	508-867-7135
8101389	Packard Machine Co	137 Westboro Rd	North Grafton	508-839-3828
8101411	Conic Tool & Die	19 Fairview Dr	Leicester	508-892-1317
8101417	General Machine & Tool Inc	PO Box 96	Leicester	508-892-3417
8101427	Millbury Metal Stamping Inc	175 W Main St	Millbury	508-865-2832
8101453	Ambur Machine Co Inc	PO Box 516	Northbridge	508-234-8444
8101473	A B Engineering Co	PO Box 690	Oxford	508-987-0337
8101475	DREM Machine Co	1 Harlan Dr	Oxford	508-987-5300
8101480	Line Bore Industries Inc	17 Town Forest Rd	Oxford	508-987-6509
8101485	R & R Engineering & Design	8 Marshall St	Oxford	508-987-1711
8101486	Sjogren Industries Inc	PO Box 624	Oxford	508-987-3206
8101487	T & D Specialties Inc	PO Box 13	Oxford	508-987-8344
8101499	C M T Machine Co	238 Cherry St # B	Shrewsbury	508-845-6011
8101502	Derbyshire, F W Inc	910 Boston Tpke	Shrewsbury	508-842-8319

8101512	Quinsigamond Machine Co Inc	122 N Quinsigamond Ave # A	Shrewsbury	508-757-2500
8101517	Whatman Inc	240 Cherry St	Shrewsbury	508-842-7111
8101520	Apco Machine Co	PO Box 1154	Sturbridge	508-347-2811
8101531	Johnson Tool & Manufacturing	246 Worcester St	Southbridge	508-765-0916
8101532	L & M Machine	817 Alpine Dr	Southbridge	508-765-1379
8101534	Metal Craft Machine Co	32 Dupaul St	Southbridge	508-764-1535
8101536	Model-Tech Inc	PO Box 241	Southbridge	508-765-9388
8101537	Myriad Engineering Co Inc	134 Ashland Ave	Southbridge	508-765-0683
8101549	Stanco Tool & Die Co	PO Box 490	Southbridge	508-764-2594
8101550	T Tool Inc	831 Main St	Southbridge	508-764-2896
8101568	Apple Pattern Co Inc	PO Box 923	Sterling	978-422-8223
8101576	Stromberg Tool & Machine Co	PO Box 578	Sterling	978-422-8178
8101599	Renault Machine & Tool Co Inc	616 Douglas St	Uxbridge	508-278-2439
8101601	Alumi-Nex Mold Inc	155 Chase Ave	Webster	508-949-2200
8101606	D & K Machine Co	PO Box 67	Webster	508-987-9650
8101623	Kokos Machine Co	75 Oxford Ave	Dudley	508-943-2700
8101630	American Machine Co	58 Hopkinton Rd	Westborough	508-366-9634
8101641	R C J Machine Co	108 Milk St	Westborough	508-366-0126
8101643	Silna Machine Co	PO Box 808	Westborough	508-366-5005
8101646	United Automation Technology	PO Box 624	Westborough	508-366-4412
8101648	Westboro Machine Co	66 Hopkinton Rd	Westborough	508-366-9729
8101662	Tomkins Corp	1 Main St	Whitinsville	508-234-4581
8101667	Green Machine Co Inc	5 Providence Rd	Sutton	508-865-6333
8101669	Marble Run Manufacturing	44 Marble Rd	Sutton	508-865-3704
8101670	Marshall Tool & Die Inc	85 Dudley Rd	Sutton	508-865-0217
8101674	S & S Assembly Inc	PO Box 116	Sutton	508-865-0687
8101690	Micrometals Technology Corp	12 Jacques St	Worcester	508-792-1615
8101692	Miniature Tool & Die Inc	127 Cambridge St	Worcester	508-756-5337
8101696	Hardiman Tool & Die Inc	9 Sutton Ln	Worcester	508-756-7912
8101698	Plymouth Wire & Cable Co	1219 Main St	Worcester	508-791-3456
8101702	Sancliff Inc	PO Box 88	Worcester	508-795-0747
8101705	Stafford Special Tools Co	217 Stafford St	Worcester	508-755-5302
8101708	A C Manufacturing Co Inc	100 Fremont St	Worcester	508-752-0501
8101714	Accudie Inc	532 Franklin St	Worcester	508-756-8482
8101716	A & G Machine Co	638 Franklin St # B	Worcester	508-752-7611
8101725	Gallant Machine Works Inc	PO Box 2301	Worcester	508-799-2919
8101743	R & D Precision Machine Co	230 SW Cutoff	Worcester	508-752-1998
8101764	Carrier, F Co Inc	38 Harlow St	Worcester	508-755-3501
8101785	Central Steel Rule Die Co Inc	46 W Mountain St	Worcester	508-853-2663
8101800	Roger Tool & Die Co Inc	33 Pullman St	Worcester	508-853-3757
8101805	Greif Bros Corp	6 Dexter St	Worcester	508-754-8913
8101809	Vangy Tool Co Inc	621 Millbury St	Worcester	508-754-2669
8101813	C & C Metals Engineering Inc	8 Nebraska St	Worcester	508-757-1120
8101827	Olympic Trophy Manufacturing	204 Main St	Worcester	508-754-3293
8101835	Worcester Precision Inc	51 Union St	Worcester	508-791-1316
8101852	A N C Tool & Manufacturing	95 Grand St	Worcester	508-757-0224
8101859	Corob Corp	95 Grand St	Worcester	508-798-8825
8101863	Edco Drilling & Honing	49 Hermon St	Worcester	508-756-5446
8101871	Mac Machine	24 Woodward St	Worcester	508-752-4131
8101876	Pilgrim Tool & Die Co Inc	565 Southbridge St	Worcester	508-753-0190

8101885	Stevens, S P Manufacturing		PO Box 902	Worcester	508-757-4563
8101918	D C M Services		21 Blandin Ave	Framingham	508-620-9914
8101920	D M Steel Rule Die Co		59 Fountain St	Framingham	508-879-4166
8101934	G Q Machine Inc		61 Endicott St # 34	Norwood	781-762-4414
8101942	J E M Manufacturing Corp		225 Arlington St	Framingham	508-872-9299
8101983	Higgins, J R Associates		898 Main St	Acton	978-266-1200
8101986	M D Machine Co Inc		916 Main St	Acton	978-264-9999
8102017	J & R Machine Co Inc		9 Alfred Rd	Ashland	508-881-2981
8102022	B & K Enterprises Inc		223 Main St	Ashland	508-881-1168
8102069	Acadian Utilities Inc		74 Commonwealth Ave	Concord	978-369-4810
8102108	Healard Machine Co Inc		163 Woodland St	Holliston	508-429-2687
8102109	Heidele Manufacturing Co Inc		PO Box 6736	Holliston	508-429-5365
8102110	Cockrill, H G Co		349 Fiske St	Holliston	508-429-2005
8102117	Melco Inc		50 Whitney St	Holliston	508-429-2626
8102120	Reklaw Machine Inc		229 Lowland St	Holliston	508-429-6071
8102121	Roar Industries Inc		120 Jeffrey Ave	Holliston	508-429-5952
8102127	Axxis Machine Inc		1 Airport Dr # A	Hopedale	508-473-8901
8102141	Phoenix Precision Inc		312 Main St	Hudson	978-562-4599
8102148	Assabet Machine Corp		PO Box 467	Hudson	978-562-7992
8102149	Bryco Machine Inc		83 Central St	Hudson	978-562-7882
8102159	Machining For Electronics Inc	HQ	PO Box 149	Hudson	978-562-7554
8102163	Orion Precision Machining		56 Hudson St	Northborough	508-393-6930
8102166	Phil Coin Machine & Tool		53 Houghton St	Hudson	978-562-7264
8102172	Saliga Machine Co Inc		10 Bonazzoli Ave	Hudson	978-562-7959
8102173	Seymour Associates		9 Bonazzoli Ave # 7	Hudson	978-562-1373
8102183	D & L Machine		PO Box 445	Hudson	978-568-0565
8102184	J W Tool Co Inc		17 Bonazzoli Ave	Hudson	978-562-5611
8102208	J & H Precision Inc		84 Chestnut St	Marlborough	508-624-6441
8102209	J & J Machine		PO Box 702	Marlborough	508-481-8166
8102216	M C S Automotive Machine		729 Farm Rd	Marlborough	508-481-5071
8102231	Roche Tool & Die Corp		170 Maple St	Marlborough	508-485-6460
8102245	S P Machine Co		1 Hammond St	Southborough	508-481-7358
8102257	West Hill Machine Corp		30 Cape Rd	Mendon	508-478-2900
8102283	Volpe Tool & Die Inc		23 Maple St	Milford	508-473-5757
8102296	Black Diamond Saw & Machine		81 North Ave	Natick	508-653-4480
8102301	Dyko Tool Die Corp		89 Washington Ave # G	Natick	508-650-9701
8102305	Eric's Machine Shop		82 S Main St	Natick	508-655-2448
8102314	J & S Machine Co		23 Willow St # C	Natick	508-655-0660
8102342	Nold, Walter Co Inc		24 Birch Rd	Natick	508-653-1635
8102346	Dougherty Tool Co Inc		148 Marlboro Rd	Southborough	508-485-5566
8102371	B M I Inc		26 Autumn St	Sudbury	978-443-4968
8102400	Bomak Corp		6 Jefferson Ave	Woburn	781-935-4100
8102414	Domino Inc		4 Gill St	Woburn	781-938-7445
8102425	Friday Engineering Inc		35 Industrial Pkwy	Woburn	781-932-8686
8102429	Hartnett Co Inc	HQ	951 Main St	Woburn	781-935-2600
8102434	J G Machine Co		7 Sullivan St	Woburn	781-935-4842
8102437	Keen Machine Co Inc		271 Salem St	Woburn	781-932-4120
8102444	Marver Cam Co Inc		20 Torrice Dr	Woburn	781-933-5858
8102454	Manufacturing Technologies Inc		11 Cranes Ct	Woburn	781-935-5588
8102458	North Woburn Machine Co Inc		10 Nichols St	Woburn	781-933-8646

8102459	N P Molds	56 Dragon Ct	Woburn	781-938-1270
8102471	Profile Engineering & Machine	PO Box 2437	Woburn	781-933-0701
8102502	Kraft, W A Corp	199 Wildwood Ave	Woburn	781-938-9100
8102504	Wells Machine Co Inc	4 Cedar St	Woburn	781-935-1560
8102508	Micro-Medic	34 Sullivan Rd	North Billerica	978-663-3449
8102518	Cambridge Machine Co Inc	315 New Boston St	Wilmington	781-938-3884
8102537	Galaxie Laboratories Inc	18 A St	Burlington	781-272-3750
8102538	Getov Machine Inc	78 Blanchard Rd	Burlington	781-229-6676
8102553	Ross Enterprises	PO Box 67	Burlington	781-272-0175
8102613	Adax Machine Co	275 Billerica Rd	Chelmsford	978-256-1155
8102625	Lake Engineering Inc	PO Box 107	Nutting Lake	978-663-9083
8102626	Resonance Research Inc	10 Cook St	Billerica	978-671-0811
8102627	Axis Technologies Inc	27 Industrial Ave	Chelmsford	978-250-9909
8102632	Center For Precision Machining	10 Elizabeth Dr	Chelmsford	978-256-8822
8102633	Cunningham Machine Co	35 Hunt Rd	Chelmsford	978-256-7541
8102640	Laser Productions	200 Turnpike Rd	Chelmsford	978-250-9345
8102646	Grind Co Inc	PO Box 192	Chelmsford	978-256-4378
8102650	P & J Precisions Machining	133 Stedman St	Lowell	978-452-9774
8102653	R & R Trophy & Engraving Corp	8 Fletcher St	Chelmsford	978-256-0938
8102655	S & H Engineering Inc	PO Box 262	Chelmsford	978-256-7231
8102663	Whitney Systems Inc	53 Parkhurst Rd	Chelmsford	978-937-7444
8102664	Winco Inc	15 Alpha Rd	Chelmsford	978-256-0982
8102686	Shepherd's Tool & Machine Shop	346 Salem Rd	Dracut	978-689-9942
8102687	Sonko Machine Co	1633 Bridge St	Dracut	978-454-5281
8102689	Universal Machine & Tool	30 Darrin Rd	Dracut	978-957-4338
8102695	Braley & Walker Inc	4 Stevens St	Haverhill	978-373-3843
8102715	A T C Screw Machine Inc	419 River St	Haverhill	978-374-7051
8102736	Stoller, Harry & Co Inc	113 Essex St	Haverhill	978-373-6838
8102739	Quality Die Cutting Inc	506 River St	Haverhill	978-374-8027
8102745	C & L Tool Inc	PO Box 121	Georgetown	978-352-2506
8102764	Hoague Sprague Leasing Co Inc	PO Box 8221	Haverhill	978-374-9060
8102766	Ital-Tech Engineering Co Inc	65 Avco Rd # B	Haverhill	978-373-6773
8102774	Sim Precision Machine Inc	12 Duncan St	Haverhill	978-374-1491
8102776	Spring Hill Machine Co	155 Neck Rd	Haverhill	978-374-4461
8102828	A & S Machine Shop Inc	60 Pine St # G	Methuen	978-794-4444
8102844	Milltech	PO Box 614	Methuen	978-686-1501
8102847	Sandor Tool & Manufacturing Co	18 Ballard Rd	Lawrence	978-683-1921
8102858	Difeo Machine Co	23 Offer St	Bradford	978-374-9578
8102864	H & H Engineering Co Inc	6 Pine St	Methuen	978-682-0567
8102866	Labombard Corp	PO Box 695	Methuen	978-688-7773
8102935	Cahill Machine	115 Congress St	Lowell	978-937-8137
8102941	High Tech Machinists Inc	25 Industrial Ave	Chelmsford	978-256-1600
8102947	Lowell Precision Machining Inc	45 Dix St	Lowell	978-453-7230
8102961	Trilap Co Inc	649 Lawrence St	Lowell	978-453-2205
8102966	Wie Sic Machining Inc	60 Foot Of Crosby St	Lowell	978-454-5627
8102971	Sequel Systems Inc	PO Box 693	Lowell	978-454-5495
8102977	Gosselin Machine Inc	95 Rock St	Lowell	978-452-0080
8102997	Alpine Precision Inc	3 Executive Park Dr	North Billerica	978-667-6333
8103000	Braze-All Engineering Co	55 High St # 2	North Billerica	978-667-6655
8103008	Duborg Jens Co	19 Sterling Rd	North Billerica	978-667-4848

8103010	Microwave Components Spec Inc	PO Box 138	North Billerica	978-667-1215
8103011	Nashoba Valley Manufacturing	34 Sullivan Rd # 27	North Billerica	978-670-5356
8103015	Patriot Machine & Engineering	11 Esquire Rd	North Billerica	978-667-8737
8103018	P T P Machining	25 Sullivan Rd	North Billerica	978-663-9004
8103022	Welfab Inc	100 Rangeway Rd	North Billerica	978-667-0180
8103037	Norus Manufacturing Co	197 Main St	North Reading	978-664-1850
8103041	Pacetti Corp	4 Hallberg Park	North Reading	978-664-2802
8103051	Mer Co	16 Osborne Ave	Reading	781-944-7399
8103071	Cooper Machine & Design Co	36 Hillman St # 13	Tewksbury	978-858-0485
8103090	Tri/Star Machining Co	2297 Main St	Tewksbury	978-694-9979
8103091	Q C M Inc	836 North St	Tewksbury	978-858-3550
8103092	Vier-Eck Machine & Tool Co	830 Livingston St # 4	Tewksbury	978-640-1714
8103093	Wamesit Engineering Service	89 Trull Rd	Tewksbury	978-858-0448
8103109	Unitec Engineering Inc	20 Cummings Rd	Tyngsboro	978-649-4500
8103118	Dimension Magnetics	103 Foundry St	Wakefield	781-245-4879
8103120	Greene, D S Co Inc	PO Box 239	Wakefield	781-245-2644
8103122	Ferro Ceramic Grinding Co Inc	PO Box O	Wakefield	781-245-1833
8103127	Lake Manufacturing Co Inc	4 Railroad Ave	Wakefield	781-245-7630
8103138	Russell Badge Manufacturing Co	PO Box 144	Wakefield	781-245-0975
8103153	Beta Machine & Tool	496 Groton Rd	Westford	978-692-2993
8103173	Sarcan Manufacturing Co Inc	12 Tripp St	Framingham	508-875-0203
8103179	A & A Machine Corp	20 Riverside Ave	Danvers	978-774-0331
8103198	High Tech Machine & Tool Inc	218 Andover St	Wilmington	978-657-8266
8103201	Lockhart Machine Co Inc	287 Main St	Wilmington	978-658-5249
8103202	L P Brazing Inc	210 Andover St	Wilmington	978-658-2295
8103206	Micro-Med Inc	200 Andover St # E	Wilmington	978-657-4140
8103207	Myron Engineering	200 Andover St	Wilmington	978-657-4067
8103231	Bennett, R L Machine Co	95 Hemingway St	Winchester	781-729-5590
8103249	Newtomics Inc	18 Mount Vernon St	Lynn	781-598-6450
8103254	Temco Corp	45 Suffolk St	Lynn	781-595-2681
8103286	Crateau Engineering	271 Western Ave	Lynn	781-593-7041
8103317	Colonial Machine Co	6 Vine St	Saugus	781-233-0026
8103322	Herb-Com Machinery Co Inc	6 Bow Street Ext	Saugus	781-233-2755
8103329	O' Connell Machine	229 Hamilton St	Saugus	781-233-4000
8103332	Stone, L E Co	23 Pleasant Ave	Saugus	781-233-1153
8103347	Challenge Engineering Inc	271 Lions Mouth Rd	Amesbury	978-388-4611
8103348	Christesen Machine Co Inc	40 Haverhill Rd	Amesbury	978-388-9021
8103349	Dalton Manufacturing Co	PO Box 3	Amesbury	978-388-2227
8103351	Frontier Machine Co Inc	8 Industrial Way	Amesbury	978-388-4466
8103354	Old Newbury Crafters Inc	36 Main St	Amesbury	978-388-0983
8103357	R E P Tool & Die Inc	5 Noel St	Amesbury	978-388-5410
8103369	Bematek Co	12 Tozer Rd	Beverly	978-927-2179
8103379	Cousins Machine Co Inc	117 Elliott St	Beverly	978-927-5718
8103380	Crane Precision Machine Inc	93 Park St	Beverly	978-922-9183
8103387	H B S Products Inc	181 Elliott St	Beverly	978-921-1440
8103392	Kausel's Engineering	64 Neptune St	Beverly	978-927-7626
8103394	Machine Technology Co	PO Box 57	Beverly	978-927-1900
8103397	Naugler Mold & Engineering Inc	60 Dunham Rd	Beverly	978-922-5634
8103405	Hueter, R Co	416 Cabot St	Beverly	978-927-3482
8103416	Fitzgerald Metal Products Inc	PO Box 255	Beverly	978-927-1284

8103418	Vector Engineering Ltd		116 Topsfield Rd	Wenham	978-468-0530
8103421	Woodman Precision Engineering		200 Cummings Ctr # 117Q	Beverly	978-927-6441
8103422	Yankee Technology Co		54 W Dane St # D	Beverly	978-922-6993
8103425	Advanced Engineering Corp		19 River St	Beverly	978-927-8900
8103432	Adams Development & Machine		3 Canal St	Danvers	978-774-3738
8103433	A-Plus Engineering		9 Old Right Rd # F	Ipswich	978-356-7587
8103435	Auto Industrial Machine Inc		9 Riverside Ave	Danvers	978-777-3772
8103438	Bratt Machine Co		1980 Turnpike St	North Andover	978-557-1041
8103442	Cunningham Engineering Inc		370 Andover St	Danvers	978-774-4169
8103443	Danvers Engineering Co Inc		88 Holten St	Danvers	978-774-7501
8103445	Hannah Engineering Co		150 Maple St	Danvers	978-777-5892
8103447	Hollis Manufacturing Inc		15 Mill St	Danvers	978-777-7925
8103454	Micronics		140 Elliott St	Beverly	978-524-0022
8103462	New England Products		151 Foundry St	Wakefield	781-245-7779
8103467	Progressive Steel Rule Die		250 North St	Danvers	978-774-6776
8103468	Red-Tee Corp		7 Bridge St	Danvers	978-774-0120
8103475	Triple S Machine		19 Warren St	Danvers	978-774-0354
8103476	T S C Precision Machining		PO Box 265	Danvers	978-777-3184
8103482	Armstrong Machine Co Inc		10 Cheever St	Danvers	978-762-0061
8103483	B & P Machine Inc		PO Box 305	Essex	978-468-3515
8103484	Collins Manufacturing Inc		239 Western Ave	Essex	978-768-7721
8103488	Semcon Machine Co		245 Western Ave	Essex	978-768-7880
8103489	Turner & Walima Manufacturing		191 Western Ave	Essex	978-768-6472
8103490	Jeto Engineering Inc		156 Eastern Ave	Essex	978-768-7618
8103491	Tracey, Wilbur Associates Inc		15 Kondelin Rd	Gloucester	978-282-1999
8103494	Benco Precision Machining		10 Pond Rd	Gloucester	978-281-2055
8103505	E M S Machine Co		743 Western Ave	Gloucester	978-525-2110
8103516	P M S Manufactured Products		10 Sadler St	Gloucester	978-281-2600
8103518	Patulak Machine Corp		80 Grove St	Gloucester	978-283-8300
8103519	R L Machine Co		9 Butman Ave	Gloucester	978-283-4384
8103544	Avtech Engineering		134 Town Farm Rd	Ipswich	978-356-5335
8103545	B & M Machine Co Inc		46 Mitchell Rd	Ipswich	978-356-2564
8103547	Castle Machine Co		59 Old Right Rd	Ipswich	978-356-2151
8103552	Ipswich Machine Associates		PO Box 1	Ipswich	978-356-0556
8103555	Kodiak Machine Co Inc		PO Box 595	Ipswich	978-356-9876
8103557	Little Enterprises		31 Locust Rd	Ipswich	978-356-7422
8103566	Target Machine Co		36 Mitchell Rd # C	Ipswich	978-356-7373
8103608	G B Engineering		PO Box 929	Middleton	978-774-3122
8103609	Island Machine & Design		PO Box 232	Middleton	978-774-9120
8103633	Hi-Tech Hose Inc		7 Opportunity Way	Newburyport	978-462-8888
8103637	Mac Diarmid Machine Co		5 Perry Way # 7	Newburyport	978-465-3546
8103640	Northeast E D M Co		4 Mulliken Way	Newburyport	978-462-4663
8103646	Taitronics		1 Harris St	Newburyport	978-462-7343
8103647	Techfab Co		4 Malcolm Hoyt Dr	Newburyport	978-465-4080
8103648	Thomas Machine Works Inc		7 New Pasture Rd	Newburyport	978-462-7182
8103649	Unigear		3 Graf Rd	Newburyport	978-463-4444
8103666	Clipper Trophies		141 Bridge Rd	Salisbury	978-462-0275
8103668	D E B Tool		PO Box 5021	Salisbury	978-462-7347
8103669	Ditech Group	HQ	PO Box 320	Byfield	978-463-0665
8103681	Boyle Machine & Supply Co		PO Box 352	Peabody	978-531-1920

8103697	General Products & Gear Corp	120 Haverhill St	Rowley	978-948-8146
8103717	Plus One Corp	PO Box 673	Peabody	978-532-3700
8103721	Riverside Engineering Inc	12R County St	Peabody	978-531-1556
8103752	Smith Brothers Machine Co Inc	PO Box 391	Rockport	978-546-7880
8103754	A B C Machine Tool Co	399 Main St	Rowley	978-948-3316
8103759	Eastern Science Co Inc	PO Box 774	Rowley	978-948-7300
8103760	F L C Machined Products Co Inc	47 Main St	Rowley	978-948-7525
8103766	P D C Machine Inc	54 Warehouse Ln	Rowley	978-948-7082
8103767	R & D Engineering Services Inc	445 Newburyport Tpke	Rowley	978-948-2751
8103770	S M B Machine Co	79 Boxford Rd	Rowley	978-948-7624
8103782	Brentwood Machine Co Inc	20 Broadway Ave	Ipswich	978-356-9889
8103788	Denmar Precision Machine Co	PO Box 952	Salem	978-744-3184
8103811	Ramco Precision Machining	416 Cabot St	Beverly	978-921-4600
8103822	Tucker Engineering Inc	1 5th St	Peabody	978-532-5900
8103840	New England Carbide Inc	428 Boston St	Topsfield	978-887-0313
8103842	Pulsar Engineering & Mfg Corp	424 Boston St # A	Topsfield	978-887-8556
8103853	Accu-Dyne Machine Tool Inc	128 Mendon St	Bellingham	508-966-3110
8103854	A D & G Enterprises Co	26 Pearl St	Bellingham	508-966-4055
8103855	Antron Engineering & Machine	PO Box 619	Bellingham	508-966-2803
8103865	Marchand Machine Works Inc	435 Wrentham Rd	Bellingham	508-883-4040
8103870	Van-Wal Machine Inc	PO Box 800	Bellingham	508-966-0733
8103871	Ideal Engineering Co	PO Box 402	Bellingham	508-966-2324
8103884	Ideal Instrument Co Inc	863 Washington St	Canton	781-828-0881
8103885	Kessler Machine Works Inc	283 Neponset St	Canton	781-828-0134
8103895	Chandler, R A Co Inc	901 Turnpike St	Canton	781-821-1300
8103908	Tri-Tech Machine Inc	960 Turnpike St	Canton	781-828-7316
8103909	Tuco Grinding Corp	PO Box 158	Canton	781-828-9200
8103947	Villa Machine Associates Inc	61 McDonald St	Dedham	781-326-5969
8103948	Wemco Machine Inc	68 McDonald St	Dedham	781-329-1122
8103954	Commercial Gear & Sprocket Co	618 Washington St	East Walpole	508-668-1073
8103969	Al's Machine Shop	621 E Central St	Franklin	508-520-1207
8104008	Mac Kenzie Machine & Design	200 Weymouth St	Rockland	781-982-8005
8104018	Superior Truck & Auto Supply	84 Accord Park Dr	Norwell	781-982-2700
8104051	Silva Machine Co	201 Oak St	Pembroke	781-826-9119
8104063	Waco Machine	106 Adams St	Medfield	508-359-6894
8104075	W B W Screw Co	126 Holliston St	Medway	508-533-6667
8104082	Weatherhead Machine Co	1060 Main St	Millis	508-376-5684
8104086	Technical Hardfacing/Machining	PO Box 479	Norfolk	508-384-6127
8104111	Coughlan Machine Inc	33 Clark St	Norwood	781-769-9900
8104133	Norwood Machine Works Inc	26 Endicott St	Norwood	781-769-0830
8104151	Barry Machine	265 Gannett Rd	Scituate	781-545-6610
8104168	A & J Machine	1600 Washington St	Stoughton	781-341-0896
8104191	Machine Inc	879 Turnpike St	Stoughton	781-297-3700
8104192	Mair-Mac Machine Co	86 N Montello St	Brockton	508-895-9001
8104201	Absolute Steel Rule Die Co Inc	187 Page St # 5	Stoughton	781-344-9743
8104220	A & W Instruments Inc	PO Box 109	Walpole	508-668-5796
8104223	Dale Tool & Die Co Inc	290 Stone St	Walpole	508-668-3550
8104467	Robinwood Studios	46 Waltham St	Roxbury	617-695-9334
8104504	Kern Co	2A Wigglesworth St	Roxbury	617-566-1272
8104538	Engine Machine Service	1584 Blue Hill Ave	Mattapan	617-298-1865

8104557	Moore, H E Co Inc	485 E 1st St	Boston	617-268-1262
8104578	Smith, George B & Sons Inc	404 Dorchester Ave	South Boston	617-268-5660
8104586	A C Tool Co	11 Walley St	East Boston	617-569-3945
8104593	Continental Machine Products	11 Walley St	East Boston	617-567-7396
8104597	Design Products & Instruments	156 Porter St	Boston	617-569-1108
8104598	Diamond Tool & Die Co	946 Saratoga St	East Boston	617-567-3313
8104621	K T Machine Products	191 Main St	Charlestown	617-776-4608
8104651	Trico Machine Co	128 Brookside Ave	Jamaica Plain	617-524-0995
8104687	United Automotive Co Inc	318 Lincoln St	Allston	617-254-3395
8104716	Gundal, Joseph E Manufacturing	445 Metropolitan Ave	Hyde Park	617-361-3188
8104735	Comstock & Wescott Inc	765 Concord Ave	Cambridge	617-547-2580
8104822	Scientific Models Inc	32 Cottage Park Ave	Cambridge	617-354-1530
8104845	Intelligent Automation Systems	149 Sidney St	Cambridge	617-354-3830
8104890	Eastern Tool Corp	35 Medford St	Somerville	617-497-4535
8104968	Gilligan Steel Rule Dies	121 Madison St	Malden	781-324-0461
8104972	Imperial Badge Co Inc	PO Box 109	Everett	781-322-2941
8104993	Quartzite Processing Inc	6 Holyoke St	Malden	781-322-3611
8105020	Atico Engineering Inc	21 Lynde St	Everett	617-389-8920
8105040	L & M Machine Inc	PO Box 6041	Chelsea	617-389-3069
8105052	Perfect Grinding Inc	167 Broadway	Everett	617-389-1044
8105084	Loyal Machine Co Inc	158 Carter St	Chelsea	617-889-2249
8105096	Wade Machine Tool Mfg Inc	120 Eastern Ave	Chelsea	617-884-2000
8105099	Davin Machining & Welding Co	PO Box 6462	Chelsea	617-884-8933
8105113	Park Products Inc	9 Dehon St	Revere	781-289-8681
8105127	Hamilton Co Inc	154 Pauline St	Winthrop	617-846-1515
8105134	Accufab Inc	81 Rumford Ave	Waltham	781-894-5737
8105138	Allston Metal Craft	18 Benefit St	Waltham	781-894-0079
8105147	Automec Inc	PO Box 519	Waltham	781-893-3403
8105155	Centerless Grinding Co Inc	38 Guinan St	Waltham	781-893-7607
8105156	Central Machine Of Waltham	40 Jones Rd	Waltham	781-893-4220
8105157	Ceramics Grinding Co Inc	74 Clematis Ave	Waltham	781-899-5200
8105159	Clematis Machine & Fixture Co	PO Box 421	Waltham	781-894-0777
8105160	C & M Tool & Die Co	36 Rumford Ave	Waltham	781-899-1709
8105163	Comptronics Inc	39 Calvary St	Waltham	781-891-4120
8105176	FMI Precision Inc	196 Newton St	Waltham	781-893-7570
8105192	Howard Clock Products Inc	256 Charles St	Waltham	781-894-0620
8105194	H & T Specialty Co Inc	PO Box 185	Waltham	781-893-3866
8105201	Kanis Machining/Manufacturing	1130 East St	Tewksbury	978-640-1700
8105216	C & A Machine	88 Maple St	Waltham	781-893-0958
8105228	Manley Precision Machining Co	1250 Main St	Waltham	781-893-4413
8105234	Rhault Die Cutting Co	214 Calvary St	Waltham	781-899-8331
8105235	Riverside Tool & Die Co Inc	11 Fox Rd	Waltham	781-890-3659
8105248	Thollden, James O & Son Inc	231 Lexington St	Waltham	781-894-2042
8105272	Electro-Freeto Manufacturing	522 Boston Post Rd	Wayland	508-358-3420
8105327	Design Shop	39 Chapel St	Newton	617-964-3990
8105348	Salco Corp	217 California St # R	Newton	617-969-7077
8105412	Production Methods Inc	PO Box 130	West Newton	617-244-1234
8105424	Sher Engraving Co	196 Beethoven Ave	Waban	617-964-9469
8105443	Marsto Machine Co	231 Willard St	Quincy	617-770-3209
8105481	B & S Engineering Co Inc	25 Hayward St	Quincy	617-471-2007

8105602	Belmar Co	78 Stone Pl	Melrose	781-662-8848
8105636	B & D Precision Inc	41 Elm St	Stoneham	781-438-8644
8105638	D R C Precision Machining Co	74 Maple St	Stoneham	781-438-4500
8105644	Proteus Manufacturing Inc	291 Salem St	Woburn	781-939-0919
8105646	Mike's Machine Co Inc	42 Elm St # 6	Stoneham	781-438-1600
8105722	South Shore Tool Engineering	194 Plain St	Braintree	781-848-4208
8105733	Alpha Die Co Inc	106 Finnell Dr	Weymouth	781-337-0099
8105734	Bees Manufacturing Co Inc	106 Finnell Dr # 7	Weymouth	781-337-1960
8105757	Moore, W P Co	65 Mathewson Dr # J	East Weymouth	781-335-9566
8105863	Ericson Machine Co	51 Melcher St	Boston	617-542-5036
8105908	Paquette Machine & Tool Co Inc	35 Bodwell St	Avon	508-587-4339
8105917	Acme Precision Machine Co	1004 Crane Ave S	Taunton	508-822-0004
8105918	S W T Inc	275 Elm St	Bridgewater	508-697-6161
8105941	C N C Wire Cut Inc	125 Highland St	E Bridgewater	508-378-7645
8105955	T M H Machining & Welding	124 Turnpike St # 15	W Bridgewater	508-580-6899
8105978	Truex Machine Co Inc	5 Pond St	Hanover	781-826-6875
8105984	Dahlberg Mold Inc	66 Hillcrest Rd	Hanson	781-293-5466
8105985	Eastern Machine & Design Corp	PO Box 120	Hanson	781-293-6391
8105988	Mixer's Shop	186 Liberty St	Hanson	781-293-6137
8105991	S & R Tool & Die Inc	5 Industrial Way	Hanson	781-447-8446
8106000	Model Engineering Corp	604 South St	Holbrook	781-767-1797
8106001	R & S Redco Inc	160 Pleasant St	Rockland	781-792-1717
8106024	Valley Machine	82 Barden Hill Rd	Middleboro	508-947-2506
8106027	Accurate Tool Machine Inc	8 Harding St	Lakeville	508-946-3414
8106036	Lecam Machine Inc	706 Brockton Ave	Abington	781-857-1044
8106042	Ar-No Machine Co	PO Box 173	North Easton	508-238-6583
8106045	North Easton Machine Co Inc	218 Elm St	North Easton	508-238-6219
8106047	Ab-Wey Machine & Die Co Inc	PO Box 567	Hanson	781-294-8031
8106066	Radii Precision Machining Inc	745 Washington St	Pembroke	781-826-6157
8106072	T M R Precision Machine Inc	300 Oak St	Pembroke	781-826-3450
8106084	Capeway Welding Inc	9 Apollo Eleven Rd	Plymouth	508-747-6666
8106122	Kingston Manufacturing Co	3 Pleasant St	Kingston	781-585-4476
8106166	Wrobel Engineering Inc	59 York Ave	Randolph	781-986-5555
8106171	Cedar Grove Bar Automatics Inc	265 Pleasant St	Rockland	781-878-1951
8106185	K & S Machine Co	PO Box 170	Rockland	781-871-0915
8106188	Med-Tech Machine Co	100 Weymouth St # G2	Rockland	781-878-2250
8106189	Milton Machine Co	992 Temple St	Whitman	781-857-1692
8106198	Russard Inc	160 Pleasant St	Rockland	781-878-4575
8106205	Cinelux Inc	570 Turnpike St	South Easton	508-238-6605
8106208	F D T Precision Machine Co Inc	400 Constitution Dr	Taunton	508-824-6863
8106209	Hanson Precision Machine	20 Hampden Dr	South Easton	508-238-0131
8106224	H & W Mold Co Inc	PO Box 445	W Bridgewater	508-583-4080
8106229	E H Metalcraft Co Inc	396 West St	W Bridgewater	508-580-0870
8106230	Moldmakers Inc	1 Old West St	W Bridgewater	508-588-4212
8106231	Parkway Manufacturing Co Inc	1 Bert Dr	W Bridgewater	508-559-6686
8106234	S T D Precision Gear & Instr	318 Manley St # 5	W Bridgewater	508-580-0035
8106240	Burnham Industries	PO Box 453	Whitman	781-447-3130
8106253	A M S Grinding Co Inc	959 W Chestnut St	Brockton	508-588-2283
8106263	Dimark	PO Box 2406	Brockton	508-580-4633
8106294	Valco Precision Machine	800 W Chestnut St	Brockton	508-559-9009

8106311	Manlie Machine Tool & Die	PO Box 3459	Brockton	508-580-1611
8106313	Modern Engineering Inc	81 Forest St	Brockton	508-583-0879
8106318	Step-Gar Engineering	227 N Cary St	Brockton	508-586-7367
8106319	T E I Co	PO Box 305	Stoughton	508-941-0776
8106321	Evans Machine Co	32 N Manchester St	Brockton	508-584-8085
8106344	Packaging Devices Inc	61 Homestead Ln	East Falmouth	508-548-0224
8106350	Cape Compass	PO Box 52	West Falmouth	508-457-9093
8106378	Graves Machine & Tool Co	Uncas Ave	Oak Bluffs	508-693-5070
8106410	D & G Machine Service	PO Box 449	Wareham	508-295-0064
8106428	ABCO Tool & Die Inc	PO Box 458	Hyannis	508-771-3225
8106431	All Cape Welders	155 Old Yarmouth Rd	Hyannis	508-771-2117
8106487	Enterprise Machine Shop	PO Box 403	Chatham	508-945-3808
8106584	B & M Engineering	6 Corporation Rd	Yarmouth Port	508-362-8335
8106591	A L & Sons Tool & Die Co Inc	67 Mechanic St	Attleboro	508-226-0788
8106592	A M I C	81 West St	Attleboro	508-222-5300
8106593	Apco Mossberg Co	104 County St	Attleboro	508-222-0340
8106599	Bergevine Brothers Inc	503 Tiffany St	Attleboro	508-222-2540
8106609	Metal Logic Inc	1840 County St	Attleboro	508-399-7656
8106617	Diversified Engineering & Mfg	PO Box 1287	Attleboro Falls	508-222-1175
8106620	Fine Edge Tool Co	13 Maynard St	Attleboro	508-222-7511
8106629	I W S Co	70 Emory St	Attleboro	508-226-2520
8106632	Ken-Grave Jewelry Services	81 West St	Attleboro	508-222-3441
8106633	K & K Machine Shop	129 Bank St	Attleboro	508-226-3170
8106638	L P M Die Co	81 West St	Attleboro	508-222-9282
8106640	M & V Tool & Die Inc	PO Box 431	North Attleboro	508-222-8169
8106643	New Age Technologies	67 Mechanic St	Attleboro	508-226-6090
8106645	North Attleboro Jewelry	112 Bank St	Attleboro	508-222-4660
8106650	Precision Tool & Machine	67 Mechanic St	Attleboro	508-222-4780
8106660	Superior Die & Stamping Co	PO Box 4070	Attleboro	508-222-1104
8106663	T D R Machine Shop	84 Lord St	Attleboro	508-399-7318
8106667	Tri-Boro Tool	65 Newcomb St	Attleboro	508-226-6161
8106671	Inman, J T Co Inc	67 Mechanic St	Attleboro	508-226-0080
8106675	Sharples, W R Co Inc	PO Box 3215	Attleboro	508-222-6823
8106689	Lizotte's Machine & Welding	12 Carpenter Ln	East Freetown	508-763-8784
8106690	Specialty Machine Co	26 Mason Rd	East Freetown	508-763-2504
8106702	Integrated Machine & Welding	74 Main St	Fairhaven	508-996-3114
8106709	Z & W Welding	PO Box 148	Fairhaven	508-996-5273
8106714	Engine Service Annex	57 15th St	Fall River	508-675-5955
8106730	Jemm Precision Technology	1567 N Main St	Fall River	508-672-0666
8106752	H & S Tool & Engineering Co	994 Jefferson St	Fall River	508-672-6509
8106761	Paramount Tool Inc	473 Pleasant St	Fall River	508-672-0844
8106786	A A Precision Machine Co Inc	621 S Almond St	Fall River	508-673-1698
8106788	A-Plus Machine	218 Shove St	Fall River	508-677-0930
8106800	R & M Precision Machine	130 Moorland St	Fall River	508-678-2488
8106804	Ferrara, N Inc	10 Riverside Ave	Somerset	508-679-2440
8106806	Accurate Machine Shop	1148 Davol St	Fall River	508-675-8821
8106831	Bobby T's Machine Co Inc	286 Herman Melville Blvd	New Bedford	508-999-0142
8106858	Harding Machine Shop	1142 Main St	Acushnet	508-763-2676
8106862	Cape Cod Staging & Equipment	97 Cove St # 33	New Bedford	508-992-2411
8106873	C & P Machine & Welding	PO Box 50247	New Bedford	508-998-2576

8106883	Ray's Of New Bedford Inc	1001 Ashley Blvd	New Bedford	508-998-1151
8106890	Aurele's Machine Co	2415 Purchase St	New Bedford	508-996-8221
8106895	Masse's Machine Co Inc	157 Coggeshall St	New Bedford	508-992-9151
8106907	Masse's Equipment	121 Coggeshall St	New Bedford	508-990-1044
8106923	Cornell & Birle Inc	6 East St	North Attleboro	508-695-6265
8106930	J D Welding & Fabricating	262 Broad St	North Attleboro	508-699-0517
8106936	Monarch Machine Works Inc	110 Broadway	North Attleboro	508-695-3300
8106946	Don's Tool & Die	141 Chestnut St	North Attleboro	508-695-7474
8106947	Stay-Sharp Tool Co Inc	229 West St	North Attleboro	508-695-8577
8106961	Premier Roll & Tool Inc	10 Alice Agnew Dr	North Attleboro	508-695-2551
8106970	Bergh Brothers Co Inc	PO Box 1206	North Attleboro	508-695-0221
8106971	Doncraft Co	PO Box 2567	North Attleboro	508-643-0558
8106975	Nelson, H P Tool Co	525 John L Dietsch Blvd	North Attleboro	508-695-9604
8106976	Neu-Tool Design Inc	140 Commonwealth Ave	North Attleboro	508-695-7280
8106978	Precision Images Inc	427 John L Dietsch Blvd	North Attleboro	508-695-0500
8106991	N & R Tool Co Inc	PO Box 471	Norton	508-285-9703
8106994	Derosier, W Mold & Machine	PO Box AD	Norton	508-823-0165
8106995	Moorehouse, W E Machine Co	166 N Washington St	Norton	508-285-7743
8107004	Raynham Tool & Die	2003 Broadway	Raynham	508-822-4489
8107007	Custom Mold & Machine Inc	PO Box 69	Raynham	508-822-7336
8107019	Micro-Tech Tool Inc	PO Box 3065	South Attleboro	508-222-5561
8107026	Thomas Steel Rule Die Making	175 Hebron Ave	Seekonk	508-761-6045
8107027	Tobin Machine & Tool	49 Industrial Ct	Seekonk	508-336-8665
8107035	Reliable Tool & Die	1720 G A R Hwy	Swansea	508-379-9752
8107057	Hi-Land Machine Co Inc	265 Bay St	Taunton	508-822-5329
8107059	K M S Machine Works Inc	485 Winthrop St	Taunton	508-822-3151
8118031	Ceric Fabrication Co Inc	PO Box 289	Monson	413-245-4522
8128609	Theriault Machine	20 Commercial Dr	Wrentham	508-384-1122
8129527	Gartman Arms Co Inc	570 Washington St	Wrentham	508-384-3791
8129583	Advanced Engine Rebuilding Inc	176 Main St	Wareham	508-295-2288
8129617	Seavey Inc	534 Boston Post Rd	Wayland	508-358-2038
8129623	Gould & Eberhardt Gear Mchry	PO Box 190	Webster	508-943-5001
8129642	Bower Manufacturing	PO Box 554	Hyde Park	617-361-5640
8113296	Masstech Molding Corp	PO Box 25	Worcester	508-756-0668
8129820	Anderson Rack & Fixture Co Inc	225 Crescent St	Waltham	781-899-4292
8129822	Apex Centerless Grinding Co	234 Calvary St	Waltham	781-893-7890
8129840	Custom Machine & Tool Co Inc	PO Box 890040	East Weymouth	781-331-7770
8129846	Stanley Engineering Co Inc	197 Ballardvale St	Wilmington	978-658-7642
8129888	D & D Manufacturing	1006 Ashburnham St	Fitchburg	978-345-0183
8129901	Metal Craft Manufacturing Inc	PO Box 80750	Springfield	413-734-9045
8129979	Kelco Metals Service Center	954 Hingham St	Rockland	781-871-1776
8130016	Eastern Reproduction Corp	PO Box 9050	Waltham	781-893-0555
8342389	B & J Machine	38 Smith St	Palmer	413-283-6649
8342394	Decker Machine Works Inc	PO Box 1	Plainfield	413-634-5005
8342402	Mohawk Model & Machine Ltd	37 Pleasant St	Southampton	413-527-3511
8342421	Valley Gage Co Inc	PO Box 259	Southwick	413-569-0103
8348788	Brennan Machine Co Inc	820 Monponsett St	Hanson	781-293-3997
8348976	B & C Tooling Co Inc	844 Bedford St	Whitman	781-447-5292
8349045	Mass Automation Corp	6 Colonel Dr	Bourne	508-759-0770
8349050	B & C Machine Co	PO Box 347	Buzzards Bay	508-759-6734

8349070	Cunniff Machine & Marine Svc	36 Round Pond Dr	East Falmouth	508-540-6232
8349134	R A M Machine	PO Box 1404	North Falmouth	508-564-7620
8349184	Off Shore Cycle & Machine	348 State Rd	Vineyard Haven	508-693-7447
8349442	Turn Wright Machine Works	791 Main St	West Dennis	508-394-0724
8349580	Pieroni Machine Co Inc	157 N Main St	Fall River	508-675-0252
8349825	B & C Automotive Machine Co	90 George Leven Dr	North Attleboro	508-643-0262
8349905	Fabiano Machine Co Inc	486 N Main St	Raynham	508-824-0948
8349956	Chiavettone, Nat Inc	702 Warren Ave	Swansea	508-336-4142
8106312	Jack's Machine	162 Industrial Blvd # 7	Hanson	781-447-9264
8342064	G & M Machine Shop	186 West St	Barre	978-355-2887
8342086	M N M Machine Co	22 Little Alum Rd	Brimfield	413-245-3408
8342187	Buckeye Tool Co	261 Garden St	Feeding Hills	413-786-5086
8342219	Specialty Machine Co	28 Commercial Dr	Hampden	413-566-8306
8342262	Professional Machine Service	PO Box 2601	Holyoke	413-552-0100
8342303	C M G Precision	45 State St	Ludlow	413-547-8124
8342316	Wallach, Raymond W	PO Box 406	Monson	413-267-4096
8342317	Century Machine	20 Wilbraham Rd	Monson	413-267-4237
8342440	Rapid Precision Machining	24 Woodland Hts	Wales	413-245-3830
8342470	A & D Metal Inc	PO Box 129	Westfield	413-562-3902
8342474	Townline General Machine Co	26 Airport Dr	Westfield	413-562-7659
8342528	Jay Tool Co	83 Spring St	W Springfield	413-788-9770
8342643	Robert's Manufacturing/Machine	279 Mill St # G	Springfield	413-733-9164
8342644	T N T Manufacturing Co	1 Allen St	Springfield	413-781-7175
8342649	Integrated Design Technology	600 Berkshire Ave	Springfield	413-747-9488
8342709	Blasioli EDM & Mold Co	703 W Housatonic St	Pittsfield	413-499-2844
8342736	Cawley Machine & Tool	1087 S Washington State Rd	Washington	413-623-8730
8342801	G & M Machine Inc	PO Box 2391	Lenox	413-232-7766
8342815	Mohawk Engineering	560 E Main St	North Adams	413-663-8474
8342822	Carr Metal Products	PO Box 29	Sandisfield	413-258-4620
8343025	Murray Machine & Fabricating	556 Mason Rd	Ashby	978-386-0075
8343040	American Screw & Barrel Inc	60 Linus Allain Ave	Gardner	978-630-1300
8343052	Accu-Speed Inc	PO Box 1008	Groton	978-448-0997
8343084	Dilling Machine Shop	122 Worcester Rd	Hubbardston	978-928-5285
8343156	Callaluca Machine Shop	31 Middlesex Dr	Littleton	978-486-0559
8343287	Walker Machine	PO Box 296	Brookfield	508-867-8097
8343328	Tinah Machine Services	122 West St	East Douglas	508-476-2047
8343358	Pro Tech Precision Machine Co	200 Mount Laurel Cir	Shirley	978-425-2000
8343362	J & N Machine Co	10 Colony Ln	Lancaster	978-534-1460
8343382	Ken-Weld & Bruno Grinding Inc	19 S Main St	Millbury	508-865-3182
8343461	R E R Machine Co	26 Russell Ln	Oxford	508-987-1380
8343462	Anderson, W S Associates Inc	PO Box 256	Oxford	508-987-0786
8343484	Kittredge Engineering Inc	577 Hartford Tpke # D	Shrewsbury	508-842-2520
8343490	Micromet Precision Tool Inc	PO Box 156	Worcester	508-757-9014
8343504	Packard, David Co	PO Box 559	Shrewsbury	508-797-9748
8343563	Albright Technologies Inc	92 Albright Rd	Sterling	978-422-8051
8343595	Tattersall Machining Inc	190 Milford St	Upton	508-529-2300
8343635	Jolie, Robert A Co Inc	PO Box 236	Southbridge	508-764-7723
8343829	Concept Tooling Inc	65 Milton St	Worcester	508-754-6466
8343849	Austin Engineering Mfg	19 Jackson St	Worcester	508-792-1122
8343897	Back To Basics Inc	69 Main St	Cherry Valley	508-892-9611

8343951	Goddard Associates	43 Little Farms Rd	Framingham	508-877-2629
8344109	Roberts Machine & Engineering	42 Flanagan Rd	Bolton	978-779-5039
8344110	Anderson Machine Co	67 Old Bay Rd	Bolton	978-779-2871
8344189	A B T Machine Co	1649 Washington St	Holliston	508-429-4355
8344272	Assabet Lapping Inc	8 Kane Industrial Dr	Hudson	978-562-5267
8344346	Monteiro Machine	9 Bonazzoli Ave # 16	Hudson	978-568-0550
8344366	Weaver's Machining Service	6 Dewey St	Maynard	978-897-9591
8344373	Stocks Machine	149 Uxbridge Rd	Mendon	508-634-1363
8344484	J & M Machine Co	40 Mount Vickery Rd	Southborough	508-460-0733
8344506	ADCO Fastening Tools	PO Box 224	Stow	978-562-2582
8344515	Chubbs Turning Inc	49 White Pond Rd # A	Stow	978-897-5119
8344638	B N K Industries	171 Merrimac St # B	Woburn	781-938-9329
8344681	A & G Centerless Grinding Co	12 John St	Woburn	781-935-5271
8344683	Apertura Corp	14 Bruno Ter	Woburn	781-933-8088
8344752	Bernoth Manufacturing Co	1 Winona Rd	Burlington	781-279-4899
8344765	Lundin Machine Co Inc	150 Wilmington Rd	Burlington	781-273-0555
8344852	D & C Precision Machine Inc	21 Progress Ave # 5	Chelmsford	978-256-1620
8344895	K B K S Precision Machining	50 Cross Rd	Dracut	978-459-9907
8344913	Unigrind Co	189 Merrimack Ave	Dracut	978-454-7836
8344958	J T Manufacturing Corp	143-145 Essex St	Haverhill	978-521-5577
8344991	P C Machine Inc	109 School St	Groveland	978-374-1210
8345222	P V Engineering & Mfg	18 Republic Rd	North Billerica	978-663-9480
8345226	TOOLROOM Inc	17 Sterling Rd # E	North Billerica	978-439-9077
8345227	Lane Machine Co	34 Sullivan Rd	North Billerica	978-262-9763
8345234	ARAM Machine Co	34 Sullivan Rd # 15	North Billerica	978-663-8511
8345239	Scott Machine	43 Letchworth Ave	North Billerica	978-663-4545
8345240	Lab Engineering/Manufacturing	16 Republic Rd	North Billerica	978-663-2475
8345252	Ree Machine Works	34 Sullivan Rd # 7	North Billerica	978-663-9105
8345253	A & G Tool & Die Inc	84 Rangeway Rd	North Billerica	978-667-0327
8345268	Ceramic Technology Inc	55 Middlesex St	N Chelmsford	978-251-1144
8345312	Lobsien Machine Co	240 Shawsheen St	Tewksbury	978-851-4264
8345338	M C Specialty Co Inc	156 Frost Rd	Tyngsboro	978-649-6490
8345342	M-Tech	67 W Tech Industrial Park	Tyngsboro	978-649-4563
8345351	Precision Technologies Inc	PO Box 610	Tyngsboro	978-649-8715
8345432	Engineered Pressure Systs Intl	187 Ballardvale St	Wilmington	978-658-1922
8345451	Komatsu Cutting Technologies	265 Ballardvale St	Wilmington	978-658-1640
8345465	Monks Manufacturing Co Inc	1 Upton Dr	Wilmington	978-657-8282
8345539	Malco	43 Alley St	Lynn	781-599-6364
8345602	MechTech Inc	PO Box 388	Amesbury	978-388-6424
8345638	Hamer Tech	300 Cummings Ctr # 428J	Beverly	978-927-4195
8345648	Whenal Machine Co	300 Cummings Ctr # 237Q	Beverly	978-921-2818
8345649	P M R Tech	93 Park St # 2A	Beverly	978-927-3905
8345679	Contract Engineering Inc	123 Park St	Beverly	978-921-0501
8345731	All American Machine	15 Mill St	Danvers	978-777-7380
8345753	Apex Manufacturing Inc	6 Scotts Way	Essex	978-768-3215
8345765	RAE-JO Machine	Rear 59 Perkins St	Gloucester	978-283-0985
8345766	Liberty Manufacturing Inc	PO Box 1403	Gloucester	978-281-7136
8345777	Paul Machine Tool	29 Magnolia Ave	Gloucester	978-525-3481
8345779	Kettle Cove Machine Co	743 Western Ave	Gloucester	978-525-3639
8345788	Gustafson Machine	7 Pond Rd	Gloucester	978-281-2012

8345822	Georgetown Machine Co Inc	38 Mitchell Rd	Ipswich	978-356-4470
8345823	Eastern Precision Machining Co	25 Plains Rd	Ipswich	978-356-2372
8345825	Chapman & Son Inc	91 Newburyport Turnpike	Ipswich	978-356-7789
8345829	Precision Resources	7 Leslie Rd	Ipswich	978-356-1091
8345851	Nichols, P M Co Inc	385 Essex St	Lynnfield	781-334-2365
8345934	Mills, J C Machine & Mfg	11 Kenney Rd	Middleton	978-777-2139
8346000	J F Machine Co	97 Beach Rd	Salisbury	978-462-9353
8346015	Covey Engineering	PO Box 2026	Peabody	978-535-4681
8346106	Micro Mation	28 Goodhue St	Salem	978-741-0118
8346159	Topsfield Tool & Engineering	PO Box 305	Topsfield	978-887-0424
8346181	DynaTech Manufacturing Co	15 Conrad Cir	Wenham	978-468-1427
8346194	L & L Tool & Die Inc	133 Blackstone St	Bellingham	508-966-3555
8346200	Wojcik, John P Wojcik Mfg Co	238 Lake St	Bellingham	508-883-8334
8346202	Dalpe's Machine Shop Inc	585 Wrentham Rd	Bellingham	508-883-4284
8346427	Atlantic Cutting Tool Inc	11 Hidden Ln	Mansfield	508-660-8995
8346455	Form Centerless Grinding Inc	106 Adams St	Medfield	508-359-2655
8346478	Jones, Harold Co	9 Chestnut St	Medway	508-533-8391
8346569	Hollingsworth, John D On Wheel	59 Davis Ave	Norwood	781-762-6004
8346651	C & P Precision Machining	380 Park St	Stoughton	781-341-0891
8346713	Neponset Valley Machine	475 West St	Walpole	508-668-4784
8347053	Wes Machine Inc	24 Chickatawbut St	Dorchester	617-288-6188
8347231	Atlantic Machine Co	45 N Beacon St	Allston	617-254-3028
8347260	Alma Industries Inc	PO Box 365506	Hyde Park	617-361-6090
8347573	Northern Centerless Inc	6 Holyoke St	Malden	781-322-4122
8347583	Malden Centerless Grinding Co	910 Eastern Ave	Malden	781-324-7991
8347826	Barc Engineering Co	215 California St Rear	Newton	617-964-6272
8348100	P S Engineering	125 Laconia St	Lexington	781-862-9106
8348558	Scientific Instrument Facility	3 Blandford St	Boston	617-353-5056
8348586	ARCO Machine	60 Pond St	Avon	508-584-3545
8348688	Exergy Inc	PO Box 209	Hanson	781-294-8838

APPENDIX G: FURTHER CNC DATA

Feeds and Speeds

The feed is the rate in which the material is removed, that is the rate in which the X, Y, or Z-axis changes position. Feeds are typically represented in inches per minute. Speeds are the rate in which the spindle is turning. The speed is expressed in revolutions peer minute.

Feeds and speeds affect the tool life, finish of the machined surface, and power required of the machine. The cutting speed is mostly determined by the material to be cut and the material of the tool (carbide, HSS etc). To find the right speed for any task a reference such as the Machinery's Handbook or other machining references will usually have pre set tables for the specific material to be cut.

The feed rate depends on the width and depth of cut, finish desired, and many different variables. If the feed rate is too low, long stringy chips that won't break will result, and if the feed rate is too high, the result will be thick chips and chip crowding or crater wear. Ideally a self-breaking chip or chips that look like 9's or 6's that are silver/blue in color will be formed.

Programming the CNC

The first thing to note is the three modes of operation; the typical CNC machine will have three modes of operation.

- Manual and Handle
- MDI or Manual Data Input
- Automatic

Manual and Handle Operation

Manual and handle operation is very similar to that of a manually operated machine. The difference is the fact that the mechanical hand wheel found on a milling machine has been replaced by control buttons or switches and by what is called a manual pulse generator.

The buttons and/or switches allow the operator to move the machine at a rapid or slow rate of speed on any or all of the axes. Some controls allow presetting the distance i.e. 0.100, 0.010, or 0.001inches.

MDI or Manual Data Input

MDI or Manual Data Input operation is one step closer to using the capabilities of the CNC machine. An operator has the ability to input single or multiple commands into the control, thus simulating a program. The MDI mode is used most often to quickly move the machine to a desired location without having to use the hand wheel. Another use is to preset a tool height.

Automatic Operation

Automatic operation is exactly as it sounds. A program is input into the control by the operator, once the program is in the machines computer interface the start button on the machine is pressed, and the program is automatically executed. This is the heart of the CNC machines purpose. It allows the operator to prepare a program in advance, verify it is what needs to be done, and run the program at an optimum speed and feed to match both the material and tooling.

G-Codes

The next thing is to explain the codes used to run the machine. This is important because EMC is a g-code interpreter for the machine. G codes are the foundation of the programming; see Appendix F for a list of some common G-codes. First, it should be understood that there are many different makes and models of CNC machines and controls on the market today. The CNC Program is made up from "BLOCKS" of information. Each block contains one or more "WORDS." A “WORD” is generally an "ADDRESS" followed by a "VALUE." The machine control executes each block in order (ex. N10, N20, N30). An example of a block is:

N20 G1 X3.0 Z-1.0 F.01 It contains the WORDS: N20, G1, X3.0, Z--1.0 F.01 the ADDRESSES N, G, X, Z, and F are used with the VALUES: 20, 1, 3.0, -1.0 and .01

Now to understand each code:

M-Codes:

M-Codes are miscellaneous commands (coolant on/off, spindle on/off, or clockwise/counterclockwise, tailstock forward/reverse, end of program. etc.)

F-Codes:

F-Codes usually represents feed rates. (I.e. F.008 or F 2.3)

S-Codes:

S-Codes usually represents spindle speeds. (i.e. S3000 max or S600 sfm)

G-codes:

G-Codes are preparatory functions and the main source (backbone) to CNC programming. G-Codes can be used (but are not limited to) rapid and linear movements (G0 & G1) (Chang, 1998).

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