DEVELOPING A MAINTENANCE VALUE STREAM MAP

Soundararajan Kannan
Yanzhen Li
Naveed Ahmed
Zeid El-Akkad
Department of Industrial and Information Engineering
The University of Tennessee,
Knoxville, TN 37996-2210

Abstract

As a result of increasing focus on lean manufacturing (henceforth referred as Lean) in today's competitive manufacturing environment, maintenance management has found a new vigor and purpose to increase equipment capacity and capability. Tremendous efforts have been put into in developing different types of maintenance strategies for enhancing the performance of the equipment but very little has been done in actually streamlining maintenance activities. This refers to systematically eliminating non-value added activities from the maintenance function. One of the primary lean manufacturing tools that can provide a different dimension in identifying and analyzing non-value added activities is Value Stream Mapping (VSM). However, the traditional VSM cannot be utilized "as is" because the maintenance activities do not completely correspond with the VSM terminology. The purpose of this paper is to develop a VSM specifically for maintenance to evaluate the non-value added activities and provide recommendations to reduce the Mean Maintenance Lead Time (MMLT).

Problem Statement

With the modern manufacturers trying to strive for Lean in order to reduce inventory, production lead time, direct labor, indirect labor, space requirements, quality costs and material costs [18], the emphasis on equipment availability has become even more critical in order for the manufacturers to successfully implement and sustain Lean. One example is cellular manufacturing, a concept of lean, in which equipments are grouped together according to the process sequence to form a cell. These cells are extremely efficient in achieving single piece flow of product but at the same time extremely susceptible. The susceptibility is due to the fact that cells are highly dependent on equipment availability. When equipment breaks down in a manufacturing cell, it shuts down the entire production line, until the equipment is brought back to its normal working condition. Hence high amount of non-value added time between machine stoppage and completion of repair, compounds the production loss.

Another dimension for streamlining maintenance activities is the cost associated with downtime. The cost of maintenance downtime as stated by Cooper [16] is typically $500 per hour for a stand-alone machine, $1,500 to $8,500 per hour for a cell or line of machines, and up to $3,500 per minute ($181,500 per hour) for an entire auto factory line. Further, the cost of downtime in lean manufacturing environment is five to thirty times more than other manufacturing environment as it directly and immediately results in lost opportunities [19]. Maintenance cost is directly proportional to the downtime hours and hence increase in the downtime hours due to non-value added maintenance activities can alarmingly increase the maintenance costs.

Thus, there is an immediate need for an approach that explicitly evaluates the maintenance function to eliminate any unnecessary time between machine stoppage and the completion of the repair function.

Literature Review

One of the primary lean tools that was found in the literature and has been effectively used in evaluating non-value added activities is VSM. It is a tool that helps in visualizing a system by the representation of information and material flow. It also creates a common language about a process, by which purposeful decisions can be made to eliminate the non value adding activities. Seven different VSM tools namely, big picture mapping (Rother and Shook, 1999), supply chain response matrix (Hines, Rich and Jones, 1997), production variety funnel (New, 1974), quality

filter mapping (Hines and Rich, 1997), demand amplification mapping (Hines and Taylor, 2000), decision point analysis (Hines, Rich and Jones, 1997) and physical structure mapping (Hines and Rich, 1997) were reviewed; however none of them directly correspond to the maintenance operations and hence cannot be applied "as is". This clearly illustrates the uniqueness of this paper, wherein for the first time ever a value stream map is introduced specifically for measuring maintenance operations.

Methodology

A general methodology that will be utilized for developing a Maintenance Value Stream Map (MVSM) is shown in Figure 1. The methodology is categorized into three distinct phases. The first phase involves developing a framework for MVSM. This framework will include all the necessary symbols that will be employed for the mapping process. The second phase involves establishing a step by step standard mapping process by which maintenance practitioners in industry could baseline maintenance activities and form a current state map of the maintenance function. The third phase involves developing a simulation model based on the current state map. The purpose of this simulation is to evaluate the non-value added activities and the efficiency of the maintenance function by incorporating variation associated with factors such as processing time and delay time
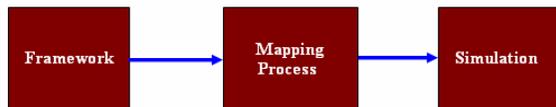

Figure 1: Methodology

Metrics for measuring maintenance

Analogous to the concept of lead time in manufacturing, the concept of Mean Maintenance Lead Time (MMLT) is being suggested for maintenance measurement. MMLT is defined as "the time between recognizing the need for maintenance on a particular piece of equipment to the actual performance of such maintenance and the repair of the equipment". [17] MMLT takes the maintenance activities into account from an operational level. Unlike the existing indicators for measuring the maintenance performance, it does not examine the impact of poor or lack of maintenance strategy on the manufacturing front; instead it acts as a powerful

tool to measure the maintenance activities themselves. The delineation of MMLT is shown in Figure 2

MMLT is given by the following equation.

$$MMLT = MTTO + MTTR + MTTY$$

Where,

MTTO = Mean time to organize (Time required to coordinate tasks to initiate the maintenance repairs)

MTTR = Mean time to repair (Time required to repair and maintain of the equipment)

MTTY = Mean time to yield (Time required to yield a good part after maintenance)
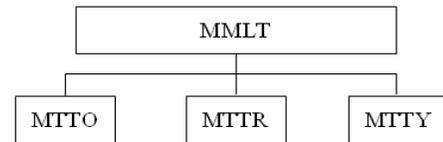

Figure 2: Delineation of MMLT

Within the MMLT delineation, the only time component that adds value to the maintenance operations is MTTR, since this is the only time component that involves the actual performance of the maintenance repair task. The other time components MTTO and MTTY are non-value added time. Hence value added time and non-value added time are given by,

$$Value\ added\ time = MTTR$$
$$Non\text{-}value\ added\ time = MTTO + MTTY$$

Maintenance Efficiency is calculated as the percentage of MMLT that is actually spent on repairing the equipment

$$\%\ Maintenance\ efficiency = \frac{MTTR}{MMLT} * 100$$

Incorporating variation into MVSM

Profozich [20] stated, "You cannot use a static tool to study a dynamic problem. A static tool gives an optimistic performance assessment. The greater the variability in the system, the greater the error in static analysis." The MVSM in essence presents a static picture of a system that breaks the maintenance function into time values (like process time, delay time etc.). In the actual scenario, all these time values are associated with some variation and as stated by Profozich [20], greater the variability associated with these time values, greater the error in static analysis. Hence for the purpose of establishing a dynamic evaluation by incorporating variation into MVSM, a simulation based approach is carried out in this paper.

Framework

In this first phase, a general framework is introduced for developing the MVSM. Within this framework there are seven categories that are utilized to represent the actual maintenance function. Specifically, these seven categories are utilized to represent MTTO, MTTR, and MTTY as presented in Table 1. Appropriate MVSM symbols are provided for each of this category. These are a combination of newly developed symbols as well as symbols adopted from the traditional VSM. The following are definitions of each of the seven categories.

1. Equipment breakdown – This activity represents the actual event of an equipment to stop production due to maintenance requirements.

2. Processes – These are actual activities that occur from the time an equipment is stopped to the time it is producing good products. In a typical maintenance operation, there are eight different processes. They are Communicate the problem, Identify the Problem, Identify the resources, Locate the resources, Generate work orders, Repair equipment, Run the equipment and Finish work order. Definitions for each of these maintenance processes are provided in Table 1. These activities represent a combination of both value added and non-value added activities.

3. Physical flow -The physical flow sequence of processes is critical to baseline the overall maintenance process. In some case the sequence of processes may illustrate opportunities for improvement.

4. Information flow – The physical flow of processes is dependent upon the flow information to enable the physical flow. It is sometimes the information that is the constraint in the system.

5. Data Boxes – Associated with each process there is a data box that provides information regarding each process. This information is critical in determining the opportunities for improvement.

6. Delay – There is a possibility of delay between any two processes. This delay is viewed as non value added that increases the MMLT and therefore the responsiveness to the customer. In a typical maintenance function, there are three different types of delay. They are Delay due to unavailability of equipment operator, Delay due to unavailability of tools and parts and Delay due to unavailability of appropriate maintenance personnel. Definitions for each of these delay types are given in Table 1.

7. Timeline – The timeline presents two categories of time. The first category is the value-added time and it is typically associated with the processes. The second category is the non-value added time and it is associated with both the processes and delays in the system.

Framework Category	Sub-Category	Symbol	Symbol Name	Definition	MMLT Category
Equipment Breakdown			Equipment Breakdown	The equipment breakdown symbol is used to represent the equipment that has shutdown.	MTTO, MTTR, MTTY
Process	Communication		Communicate the problem	This process involves the communication of the problem by the equipment operator to the maintenance personnel as soon as the equipment shuts down	MTTO
	Identification		Identify the problem	This process involves the identification of the cause of the problem for equipment shutdown	MTTO
			Identify the resources	This process involves the identification of appropriate resources such as tools, spare parts, people etc required for performing the repair work.	MTTO
	Locate		Locate the resources	This process involves locating/ordering the appropriate resources needed for the repair work.	MTTO
	Work order		Generate work order	This process involves generating a maintenance work order through the CMMS system	MTTO
			Finish work order	This process involves completing the maintenance work order through the CMMS system	MTTO
	Repair		Repair equipment	This process involves the operation of actually repairing the equipment	MTTR
	Yield		Run the equipment	This process involves the operation of an equipment after repair until a good part is produced	MTTY
Physical flow	Push Arrow [5]		Push Arrow	The push arrow represents the physical flow sequence of processes. Two subsequent maintenance processes are connected by this arrow.	MTTO, MMTR, MMTY
	Down Arrow		Down Arrow	The down arrow represents the physical flow between the shut down equipment and the first activity in value stream.	MTTO
Information flow	Manual [5]		Straight Arrow	The straight arrow represents the manual flow of information from memos, reports, or conversation. Frequency and other notes are provided along the line.	MTTO, MMTR, MMTY
	Electronic [5]		Wiggle Arrow	The wiggle arrow represents the electronic flow of information from the internet, intranets, local area network (LAN), wide area network (WAN). Frequency and other notes are provided along the line.	MTTO, MMTR, MMTY
Data box [5]			Data box	The data box is used to record the information of each maintenance process. Typical information placed in this box will be the Process time of each maintenance process	MTTO, MMTR, MMTY

Table 1: MVSM Framework

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| Framework Category	Sub-Category	Symbol	Symbol Name	Definition	MMLT Category
Delay	Unavailability of equipment operator	△1	Delay 1	The delay 1 symbol is used to represent the delay in the initiation of maintenance process due to the unavailability of equipment operator to inform the maintenance personnel about the equipment shut down.	MTTO
	Unavailability of tools & parts	△2	Delay 2	The delay 2 symbol is used to represent the delay due to unavailability of appropriate tools and parts required to perform the maintenance tasks.	MTTO
	Unavailability of appropriate maintenance personnel	△3	Delay 3	The delay 3 symbol is used to represent the delay in the maintenance process due to unavailability of appropriate maintenance personnel.	MTTO, MTTY
Time line [5]		NVA / VA / VA	Time line	The time line symbol is used to record information about value added (VA) and non value added (NVA) times Non value added times are recorded on the top of the timeline and value added activities are recorded on the bottom of the timeline.	MTTO, MTTR, MTTY

Table 1: MVSM Framework

Mapping Process

This phase describes the mapping process involved in developing the MVSM. The process is presented in the seven steps provided below:

Step 1 involves the following tasks associated with the equipment that has been shut down as presented in Figure 3.
- Draw the equipment breakdown symbol for the equipment that has shut down.
- Place this symbol at the top left hand corner of the MVSM page
- Write the equipment name at the top rectangular box.
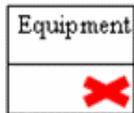
Figure 3: Step 1 of MVSM

Step 2 involves identifying the boundary of the process. Specifically this involves identifying the first process after a machine is shut down and the last process when a first good part is produced.
- The first process is associated with symbol "communicate the problem".
- Place this symbol to the left hand side of the page under the equipment breakdown symbol.
- Place the finish work order symbol to extreme right hand side of the page such that it is aligned with communicate the problem symbol as shown in Figure 4
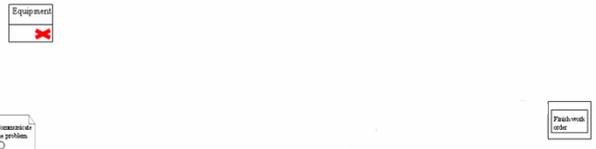
Figure 4: Step 2 of MVSM

Step 3 involves identifying the intermediate processes between the first process "communicate the problem" and the last process "Finish work order".
- Place all the intermediate process symbols namely, "Identify the problem", "Identify the resources", "Locate the resources", "Generate work order", "Repair equipment" and "Run the equipment" right next to each other according to the process sequence as shown in Figure 5.
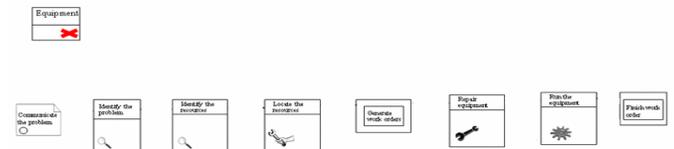

Figure 5: Step 3 of MVSM

Step 4 involves recording the information associated with each maintenance process as shown in Figure 6
- Place the data box symbol underneath each process.
- Calculate the process time for each process. The variation associated with the process time can also be recorded.
- Enter the value of the process time in the data box. Arbitrary process time values are assigned for the purpose of illustration.

It should be noted that the finish work order process does not contribute to MMLT and hence its process time is not included.
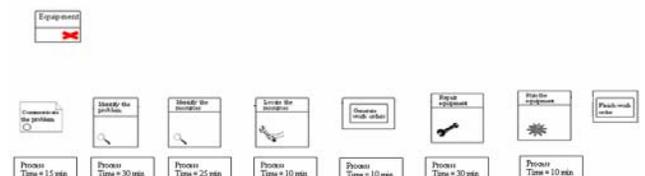
Figure 6: Step 4 of MVSM

Step 5 involves recording the delay time between maintenance processes.

- Place the delay symbol between all the processes.
- Write the appropriate numbers inside the delay symbol to indicate the type of delay. If there are two or more types of delays associated with a process, write all the numbers corresponding to the delay type separated by comma as shown in Figure 7.
- Calculate the delay time. The variation associated with the delay time can also be recorded.
- Write the delay time below the delay symbol. Arbitrary delay time values are assigned for the purpose of illustration.
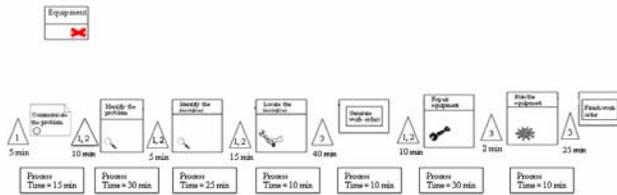
Figure 7: Step 5 of MVSM

Step 6 involves creating the physical flow and information flow for maintenance processes.

- Connect the break down equipment with the first activity in the value stream using the down arrow symbol.
- Connect all the processes with physical flow (dashed lines) and information flow (continuous line) arrows as shown in Figure 8
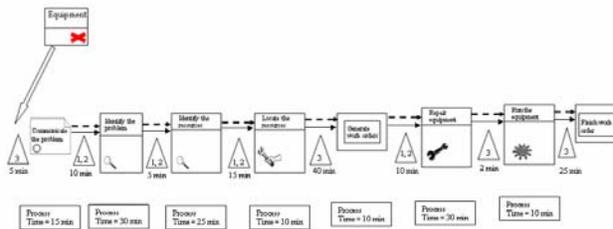

Figure 8: Step 6 of MVSM

Step 7 involves the following tasks associated with developing the time line.

- Draw the time line at the bottom of the page.
- Write down all the non-value added times at the top of the time line and all the

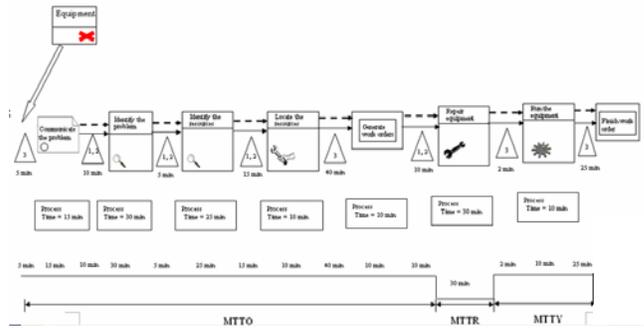value added times at the bottom of the time line as shown in Figure 9.

Figure 9: Step 7 of MVSM

Simulation

This phase involves the use of computer software to incorporate variation into the MVSM and perform a dynamic evaluation of the maintenance function. This will also provide user friendliness to the model, wherein the user can input different time values for all the delays and processes in the MVSM. The simulation will then automatically calculate MTTO, MTTR, MTTY, MMLT, non-value added time, value added time and efficiency of the maintenance function.

A simulation model for MVSM was developed using ARENA 8.0. The model receives input from the user as shown in Figure 10.
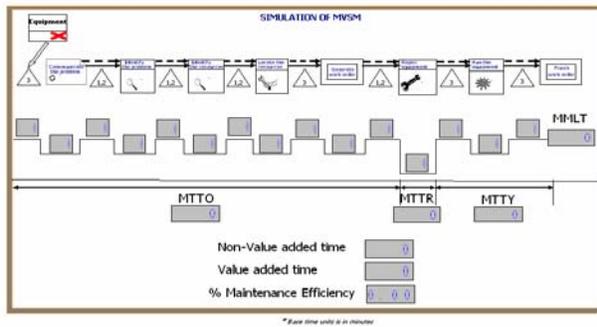

Figure 10: Simulation Input Screen

The simulation inputs; number work orders per year and time between each work order determines the number and the frequency of simulation runs required to evaluate the maintenance function. The other simulation inputs are the MVSM parameters. Values for all the simulation inputs can either be an average value or any type of distribution. Table 2 lists the

various types of distribution and the format in which it should be given as input to the model.

Type of Distribution	Input Format
Exponential	EXPO(Mean)
Normal	NORM(Mean, StdDev)
Triangular	TRIA(Min, Mode, Max)
Uniform	UNIF(Min, Max)
k-Erlang	ERLA(Expomean, k)
Beta	BETA(Beta, Alpha)
Gamma	GAMM(Beta, Alpha)
Johnson	JOHN(Gamma, Delta, Lambda, Xi)
Lognormal	LOGN(LogMean, LogStdDev)
Poisson	POIS(Mean)
Weibull	WEIB(Beta, Alpha)

Table 2: List of Distribution

After getting all the inputs from the user, the simulation automatically evaluates the maintenance function in terms of MTTO, MTTR, MTTY, MMLT, Non-value added time, Value added time and % Maintenance Efficiency. After performing all the evaluations, the simulation displays the results as shown in Figure 11.


**Figure 11: Simulation Output Screen**

Application

Tungsten powder production process as shown in Figure 12 was used as a case study to demonstrate the practical application of the proposed MVSM. The raw material used for the powder production is tungsten oxide powder. This powder is fed in to the furnace, which converts tungsten oxide into tungsten. The tungsten powder obtained from the furnace is sent to lab (Inspection 1) for determining the

grain size of the powder. Various different grain sizes of tungsten powder are blended in the blender to get the appropriate mix of grain size. The tungsten powder from the blender is then sent to the lab (Inspection 2) for a final inspection of the grain size. The inspected tungsten powder is stored in drums for shipping. The bottleneck process within this production process is the furnace operation. Since the downtime of the furnace will impact the production the most, it was decided to develop a MVSM for the furnace.
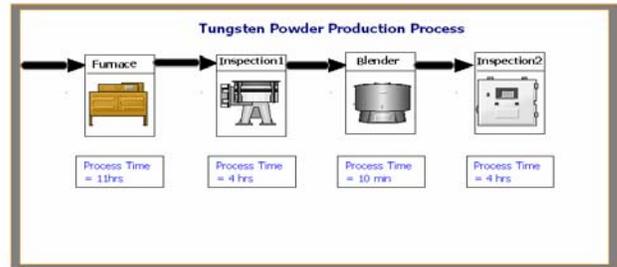
Figure 12: Tungsten Powder Production Process

Using the seven step standard mapping process, a MVSM for the furnace equipment was developed as shown in Figure 13.
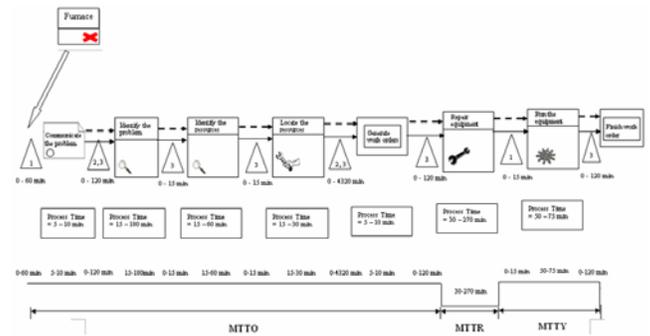

Figure 13: MVSM of Furnace

The simulation model was used to evaluate the MVSM of furnace. The simulation inputs; number work orders per year was found to be 36 to 83 and time between each work order was found to be 1 to 36 days. Normal distribution was used for all the input values.

Results and Recommendation

The results obtained from the simulation model are shown in Figure 14. MMLT is 3012 minutes, MTTO is 2742 minutes, MTTR is 143 minutes, MTTR is 127 minutes, Non-value added time is 2869 minutes, Value added time is 143 minutes and the Maintenance efficiency is 4.76%.
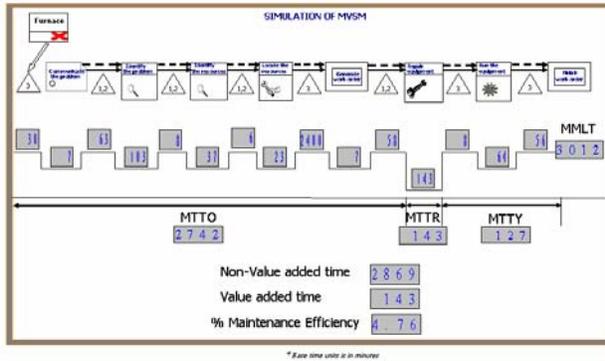
Figure 14: Simulation Results

The results suggest very low maintenance efficiency; this is predominantly due to the high amount of non-value added activities within the maintenance function. The majority of non-value added time is due to the delay between "Locate the resources" and "Generate work order" process. This delay is caused due to the unavailability of tools and parts to issue the work order to perform the necessary maintenance task. This clearly indicate that the focus point of the maintenance personnel should be to have a proper mechanism such as a supermarket pull system (an inventory control strategy of Lean) as this will ensure the availability of appropriate maintenance parts and tools at all times and will significantly streamline the maintenance activities.

Conclusion

There are several conclusions that can be drawn out of this paper. Firstly, the framework provides a list of some of the newly developed MVSM symbols, which can be universally employed by all Industrial Engineering (IE) practioners involved in mapping out the maintenance function. These symbols will also provide the IE community with a common language of addressing their maintenance activities.

The step by step standard mapping process will enable the IE practioners to successfully baseline the maintenance activities in terms of the components of MMLT, namely, MTTO, MTTR, and MTTY

The simulation model of MVSM will provide the IE practioners the capability to incorporate variation into any of the MVSM parameters and perform a dynamic evaluation of the maintenance function in terms of MMLT, MTTO, MTTR, MTTY, Non-Value added time, Value added time and Maintenance efficiency.

Overall, the IE community now has a tool by which they can effectively evaluate the maintenance function; this in essence will provide scope for reducing the areas of non-value added activities within maintenance and thereby enhancing the availability of the equipment and the capacity of the manufacturing facility.

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Biographical Sketch

1. Soundararajan Kannan is pursuing his Master of Science degree in the Department of Industrial and Information Engineering at University of Tennessee, Knoxville. His areas of research interest include lean manufacturing, lean maintenance, supply chain management, quality management, and system reliability. He has been actively involved in research paper writing, sponsored research and industrial projects.

2. Yanzhen Li is currently working as a continuous improvement engineer at La-z-boy. His areas of interest include lean manufacturing, lean maintenance, system reliability and facility maintenance.

3. Naveed Ahmed is pursuing his Master of Science degree in the Department of Industrial and Information Engineering at University of Tennessee, Knoxville. His areas of research interest include lean manufacturing, supply chain management, Scheduling and Production Control. He has been actively involved in sponsored research and industrial projects.

4. Zeid El-Akkad is pursuing his Master of Science degree in the Department of Industrial and Information Engineering at University of Tennessee, Knoxville. His areas of research interest include lean manufacturing, supply chain management, scheduling and lean office. He has been actively involved in sponsored research and industrial projects.