Effective Capacity Planning for Operations in a Contract Manufacturing Setting

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Abstract

Capacity planning is one of the most challenging yet important activities for manufacturing companies. Several different forms or resources are required for operation, including both humans and equipment. Each of these resources has a finite capacity and must be allocated to address various projects. Spikes and lulls in resource usage result in inefficiencies, timeline delays, and reduced profitability. Understanding a manufacturing company's resource capacities, planning their upcoming work, and strategically allocating those resources are essential for optimizing its production. This becomes an even more daunting task in a contract manufacturing setting because the company is reactionary to its customers' placement of orders. It is rare to foresee the exact amount of incoming work, so how can contract manufactures improve their capacity planning to avoid drastic lulls and spikes in resource utilization? Customers may provide a demand forecast to the manufacturer, but this is not frequently available. The manufacturer may also attempt to draw insight from customer order patterns, but this can only usually be attempted on a few high-order products. Multiple departments must be involved and provide input into forecasting, and the results affect multiple departments as well. However forecasting is accomplished, this expected workload must be systematically added to existing workload to understand the best way to allocate resources, take on or refuse new projects, and invest in resource capacity expansion. This paper aims to advise contract manufacturers on methods and metrics to effectively level-load their shops and increase their productivity levels.

Keywords
resource allocation, vendor-managed inventory (VMI), enterprise resource planning (ERP), level-load, bullwhip

1. Introduction
For a manufacturing company to run at its most efficient state, it must ensure that its resources are being allocated appropriately across all active projects. However, this is far easier said than done, especially in a contract manufacturing environment. Contract manufacturing is entirely dependent on customer orders. Traditional contracting involves a supplier detailing the payment scheme for a good or service depending on the customer's choice of various parameters, such as quantities, lead-time, etc. (Bolton & Dewatripont 2005). Customers place purchase orders for desired parts and assign due dates based on their demand needs and the manufacturer's quoted lead time. Beyond the initial quote, these quantities and due dates are typically independent of the manufacturer's current workload and rarely involve input from the manufacturer prior to the order. The assumption by the customer is that the manufacturer will schedule this new order into its existing workload and deliver accordingly.

Naturally, given that the work is entirely order-dependent, there will be spikes and lulls in a contract manufacturer's workload. These spikes and lulls cause inefficiencies for the company and can result in late deliveries, quality issues, and reduced profitability. Various resources are required to accomplish any project. Some examples of common resources required in manufacturing are machines/equipment, machine operators, raw material, CNC programmers, engineers, inspectors, etc. Regardless of whether a resource is human or not, it inherently has a finite capacity. As work is brought in, these resources must be strategically allocated to accomplish each project. Once the amount of work on-hand exceeds the capacity limit of any given resources, the company must prioritize.

With such a reactionary environment, how can a manufacturer attempt to maintain a level workload? There are a few things that can help accomplish this. Customer forecasting is one of the best methods of helping level-load a manufacturing shop. This involves the customers providing a heads up to the manufacturer before placing an order. They may investigate their own demands and provide an estimated future order schedule, thus allowing the manufacturer to plan and ensure it has capacity to support the future work. The manufacturer may attempt to generate its own order forecast by searching for patters in order history. This may allow them to predict and plan for orders that have not yet been placed. Finally, vendor-managed inventory (VMI) can be established to help level load a shop. These three methods of capacity planning all share a critical requirement to be effective: the forecasted work must be added to the existing workload to portray an accurate picture of a manufacturer's capacity.

Capacity planning typically begins with the Sales departments as they are the ones with the closest knowledge of potentially incoming work. However, this capacity planning will affect all departments of a contract manufacturing company. Operations must know how many machine operators and inspectors to staff. Supply Chain must know what materials and how much material is needed for existing and incoming projects. Proper implementation of the previously mentioned forecasting methods will result in increased manufacturing efficiency. Excessive costly overtime will not be required, employee burnout will be reduced, on-time deliveries will be more frequent, and quality issues will be avoided. In turn, profitability and moral will be improved, which can lead to growth opportunities for the company.

2. Literature Review

The goal of an effective demand forecast is to support a company's sales and operations planning (S&OP) efforts (Brüggen et al. 2020). This becomes even more crucial in industries where product demand is highly cyclical (Durango-Cohen & Yano 2006). Finite resources must be allocated to various projects and remain within their respective capacity limits. Forecasting is the foundation of strategic resource allocation at a contact manufacturing company. An effective forecast allows Operations to allocate resources not only to existing work, but also plan and prepare for incoming work. While a company must strive to accurately forecast incoming work, it is nearly impossible to perfectly predict a future demand. Uncertainty and error are inherent to any forecasting process. Forecasting error is the absolute-value difference between what was predicted and what occurred.

There are four factors that determine the effectiveness of a demand forecast. The forecast must be detailed in what is expected, accurate in volume, predictable in timeliness, and integrated into the company's existing workload (Bowersox et al., 2012). As previously mentioned, forecasts can be generated from a variety of sources. An aggregate forecast includes each method of forecasting to predict the total future demand of a product. Forecasts can be provided by the customer, deduced from prior sales history, or predicted from recent market trends. Forecasting often will also involve the judgement of a salesperson (Siemsen et al. 2018). A salesperson may need to use their judgement to adjust a forecast and deviate from historical data to account for any knowledge or insight they have acquired (Cassar & Gibson 2008). Approximately 70 percent of organizations include the judgement of salespeople, either completely or partially, in their aggregate demand forecasting (Brüggen et al., 2020) (Fildes et al. 2009).

Understanding its own resource capacity limits and incorporating forecasted demand into S&OP can allow a contract manufacturer to better assess the viability of a potential new opportunity (Anderson & Joglekar 2005). Contract manufacturers frequently operate in an "available to promise" (ATP) fashion (Meyr 2009). This essentially means that its resources either currently have or will have open capacity. The manufacturer promises delivery of product based on the assumptions of this future resource availability in the form of a lead-time. Violent fluctuations in resource capacity, known as bullwhip, can result in customer dissatisfaction and production inefficiencies. Each of these negative impacts will almost certainly affect profitability and business success. Therefore, the accuracy of a manufacturer's forecast is directly correlated to its potential profitability (Cederlund et al. 2007).

One of the most common and ideal forecasting methods is simply a customer-supplied expected demand. When a customer is able to supply the manufacturer with an expected demand, the level of accuracy is likely relatively high. The customer should have the keenest insight to future demand for their products (Taylor & Xiao 2010). Retailers typically use their own insight to expected selling duration and replenishment lead times to match supply with demand (Tang et al. 2004). However, manufacturers may be able to deduce their own forecasts. Deducing forecasts based on salesperson market intel and cyclical customer demand history and market intelligence allows manufactures to predict future demand before an order is placed. Depending on the amount of history and insight known, a manufacturer may have better market demand information than the customer (Kalkanci & Erhun 2012). Finally, it is well established that removing an echelon within a supply chain can effectively improve its performance, thus resulting in higher profitability for both the customer and supplier (Wikner et al. 1991). This can eliminate delays in communication and allow the manufacturer to operate at maximum efficiency with larger production runs. In such a rapidly changing and ever-expanding world, batch size and scheduling can be the difference between sustainable profitability or business failure (White & Censlive 2006). Implementing a vendor-managed inventory system is a practical method of echelon elimination in a supply chain (Disney & Towill 2003).

Once established, it is critical to add any forecasting insight to the existing workload. Ideally, this information would be entered into the company's enterprise resource planning (ERP) system. "An ERP system is a configurable information systems package that integrates information and information-based processes within and across corporate functional areas such as finance, accounting, human resources, sales and distribution, manufacturing, material procurement, and production." (Kumar & Van Hillegersberg 2000) (Razi & Tarn 2003). This aggregate workload can drive a company's resourcing decisions, including resource expansion and growth. Hiring more employees or investing in new equipment must be done prior to a firm order being placed as these resource expansions take time to occur. Effective forecasting and use of this future demand insight can be the difference between a successful or dying manufacturing company.

3. Methods

In this paper, real-life contact manufacturing company XYZ was analyzed for its resource utilization levels. XYZ was a worthy candidate for investigation for several reasons, especially its traditional contracting business practices, focus on one market, and ability to collect quantifiable data.

Contract manufacturing company XYZ operates is a traditional contracting fashion and specializes on manufacturing products for one specific market. Each of its customers are direct competitors of one another. These customers created designs of new products that they need manufactured and reach out to XYZ for quoting. This quoting involves XYZ sharing a price and lead-time that they are willing to manufacture the given part for, but this investigation will center primarily around lead-time.

Lead-time directly relates to future resource capacity and utilization. Company XYZ must estimate the amount of resource utilization a potential opportunity will require and share a competitive timeframe that they will be able to strategically allocate these resources to a project at any given time in the future.\ As previously mentioned, resources are finite. They have a maximum capacity that cannot be exceeded. However, especially when referring to human resources, this capacity is also limited by inefficiencies. It is incorrect to assume that an employee who is scheduled to work 40 hours per week will be 100% productive for all 40 hours. An employee will need to take breaks, use the restroom, assist other employees, etc. There will be inefficiencies inherent to all resources that must be considered when calculating total capacity. Equation (1) represents company XYZ's method for realistically estimating its total resource capacity with these inefficiencies.

$$\text{True Weekly Capacity} = 40\text{hrs} * N \text{ Resources} * 2 \text{ Shifts} * 85\% \text{ Efficiency} \tag{1}$$

Once XYZ has communicated a lead-time for a given potential product during quoting, it must be prepared to allocate resources to support the manufacturing of that product within that timeframe for future orders. Forecasting can provide XYZ with a significant advantage for production readiness. Obtaining insight to expected future demand and preparing its resources for orders that have not come yet can drastically increase XYZ's likelihood of meeting the customer's timeframe. This forecasting can come from multiple methods and sources and can greatly benefit all departments of the business which include customer-provided forecast, internal forecasting, and vendor-managed inventory

4. Data Collection

XYZ cannot assume that the customer will provide any forecasting prior to placing an order this is known as a customer-provided forecast**.** Like XYZ, the customer is often in a reactionary position and may not have insight to future product demand. However, on occasion, a customer may have a demand forecast. If available, it can be mutually beneficial for a customer to provide their manufacturers with their demand forecasts. The manufacturer can utilize this insight to allocate resources and make decisions for future need. If the manufacturer is able to better prepare its resources prior to a firm order placed, the customer is more likely to receive its product on-time.

Company XYZ, and other manufacturing companies, should place significant trust in any customer-provided forecast that they are fortunate enough to receive. The customer will have the most accurate insight to future demand. As the retailer, they have the closest relationship to sales patterns, product marketing efforts, current inventory levels, market fluctuations, and other variables that feed into product demand. Thus, their forecasts can be assumed to be as accurate as possible. When a customer-provided forecast is available, a manufacturer should allocate its resources nearly as firmly as they would with a hard order.

When a customer-provided forecast is not available, company XYZ and other contract manufacturers can also attempt to forecast internally, this is the process of internal forecasting. Depending on the level of historical data and market intelligence available, these internal forecasts can prove to be quite accurate.

A manufacturer can reference the order history of a given product, look for patterns, and use this data for foresee future orders. This method of forecasting is most useful when the following criteria are met:

1. The manufacturer has a significant order history to reference.
2. The customer orders the product with relatively routine frequency and quantity.
3. The product demand over time is not significantly volatile.

If a customer has typically ordered a certain quantity of a given product and places these orders in a relatively consistent frequency, the manufacturer should be able to roughly estimate the size and timing of the next order. Internal forecasting based on prior order sizes and history is limited in its application due to the fact that very few products will meet the above three assumptions. The only products that will typically be accurately forecasted by historical orders are high volume products that the manufacturer has been making for a long time.

Internal forecasting can also be accomplished by market intelligence. A salesperson is responsible for understanding the market and researching which products will be in demand. They have relationships with customers and may learn this information through conversations with them. For example, a customer may tell a salesperson of a new marketing campaign that will be beginning shortly to push a given product. The salesperson must make note of this and understand that this could mean a potential increase in demand for that product. Another example could be the knowledge of a manufacturing competitor closing its doors. This may lead to a demand for the products that company was making, or an increase in demand for XYZ if both companies were making the same product. Forecasting is not always based on data and hard numbers. It can often be based on the best judgement of an individual who has insight to the target market.

Company XYZ also utilizes a third method of allocating its resources to meet future customer demand know as a vendor-managed inventory system, or VMI. Like a customer-provided forecast, VMI involves the customer sharing its expected long-term demand for a product. However, rather than simply communicating this expected demand, the customer places long-term orders. This gives the manufacturer ample time to make the product. If they choose to make the product prior to the demand date, they simply stock the product themselves and have it ready for sale when needed.

The manufacturer can be strategic with its resources when operating in a VMI system. It may choose to wait until there are lulls in shop load and then fill these lulls by running the product, even though it is not needed by the customer for quite some time. This helps to level-load the resources and avoid the peaks and valleys of utilization. The manufacturer may also choose to run large quantities of the product to maximize its efficiency and avoid extra setups, teardown, and other non-profitable activities. VMI is used at company XYZ for products that have high market demand and will not become obsolete prior to the demand date.

5. Results and Discussion

As mentioned, the resource utilization of contract manufacturer XYZ was investigated. Shop load data was pulled from XYZ's ERP system. This data represents only XYZ's firm orders and scheduled work. Forecasted work is not included in this data because XYZ does not yet implement its forecasts into its ERP system. Table 1 portrays the raw data of XYZ's total capacity, remaining capacity, and utilization rates by resource group. It is important to note that the total resource capacities displayed in Table 1 are reflective of the adjustment for inefficiencies derived from Equation (1). As previously mentioned, it is unrealistic to assume that resources, especially human resources, will be 100% productive for the entirety of their scheduled work session.

Figure 1 is a graphical representation of XYZ's the resource utilization rates by resource group. This graph provides a visual insight to XYZ's current shop load, as well as the room it may have for forecasted and incoming work.

Table 1. Resource Utilization Metrics of Company XYZ by Resource Group.

Resource Group	Resource Metric	4/7/22 - 4/13/22	4/14/22 - 4/20/22	4/21/22 - 4/27/22	4/28/22 - 5/4/22	5/5/22 - 5/11/22	5/12/22 - 5/18/22
Finishing	**Total Capacity (hrs.)**	280	168	280	280	280	280
	Remaining Capacity (hrs.)	41	62	63	93	69	167
	Resource Utilization	86%	63%	77%	67%	76%	40%
Finishing Chemical	**Total Capacity (hrs.)**	490	294	490	490	490	490
	Remaining Capacity (hrs.)	37	22	57	147	63	211
	Resource Utilization	92%	93%	88%	70%	87%	57%
Quality Control	**Total Capacity (hrs.)**	1155	693	1155	1155	1155	1155
	Remaining Capacity (hrs.)	-48	-285	-247	170	84	249
	Resource Utilization	104%	141%	121%	85%	93%	78%
Lathe	**Total Capacity (hrs.)**	4130	2478	4130	4130	4130	4130
	Remaining Capacity (hrs.)	1021	390	1118	1099	1315	1425
	Resource Utilization	75%	84%	73%	73%	68%	65%
Milling	**Total Capacity (hrs.)**	1470	882	1470	1470	1470	1470
	Remaining Capacity (hrs.)	525	222	687	667	784	839
	Resource Utilization	64%	75%	53%	55%	47%	43%
Post Processing	**Total Capacity (hrs.)**	1120	672	1120	1120	1120	1120
	Remaining Capacity (hrs.)	294	-158	271	579	446	512
	Resource Utilization	74%	124%	76%	48%	60%	54%

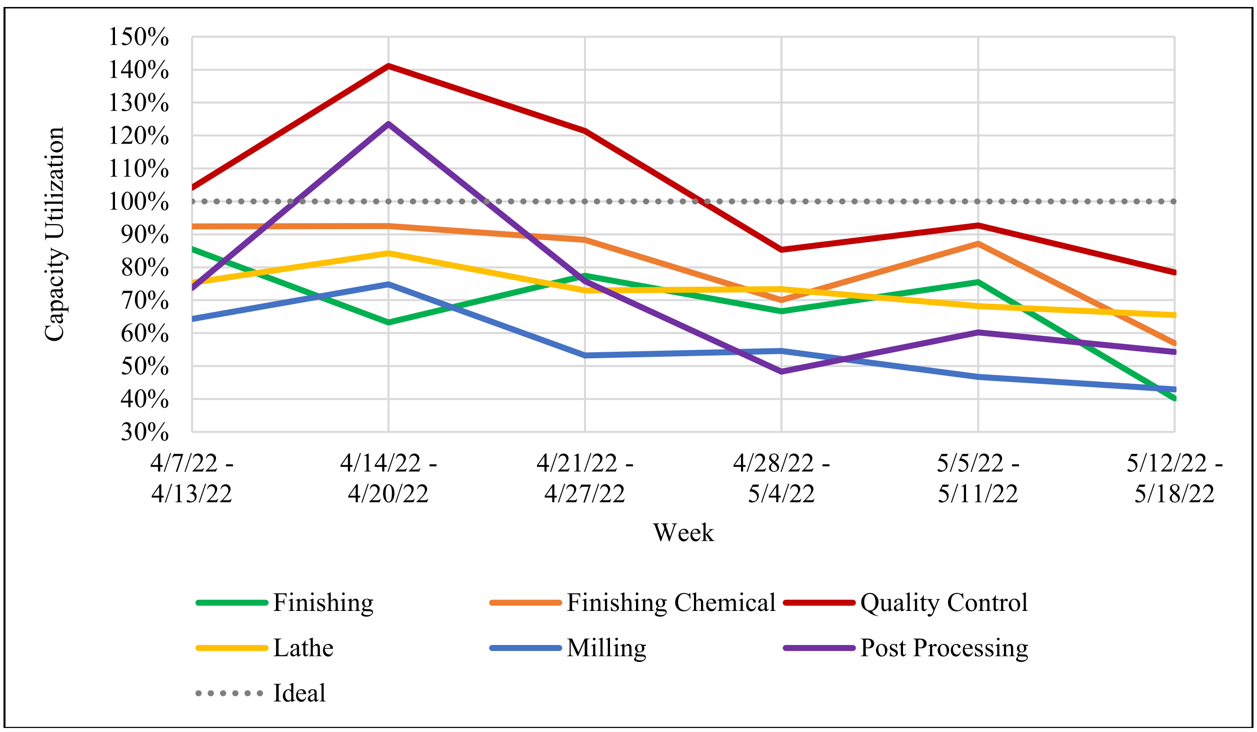

Figure 2. Resource Utilization Rates of Company XYZ by Resource Group.

There are a few important points to reflect on in Figure 2. It should be noted that there appears to be a downward trend in resource utilization across all resource groups as time moves further into the future. This is because XYZ does not yet include its forecasted and expected future work in its shop load. Once firm orders are placed, jobs are scheduled, and load is realized. While the graph may appear that the XYZ will be very light on work during the week of 5/12/22 – 5/18/22, the reality is that firm orders will be placed to increase this utilization.

Adding forecasted work to the current shop load for visualization of expected total resource needs would be tremendously beneficial to XYZ. There are clearly lulls and spikes in current resource demand. The Quality Control and Post Processing departments are clearly overutilized during the week of 4/14/22 – 4/20/22, while the Milling and Finishing departments are underutilized. If visualization to total expected resource demand was available, XYZ could begin investigating methods for level-loading the shop. If a spike in resource needs was coming, XYZ could begin asking its employees to prepare to work overtime in the coming weeks. It could also begin offering overtime in the near-term to free up resources for the weeks to come. On the contrary, if a lull in work was approaching, XYZ could capitalize on this opportunity to provide training courses for new skills, or cross-train its employees so they could assist in other resource groups when needed in the future.

5.1 Numerical Results

An aggregate forecast is the combination of any customer-provided forecast, internal forecast, or VMI system. Once established, it is crucial for a manufacturer to effectively implement this future demand into its enterprise resource planning (ERP) system. An ERP system should function as the central nervous system of a successful business.

At company XYZ, the ERP system is used to allocate all resources. Machines and equipment are scheduled, raw material is ordered, manufacturing processes are laid out, and operations are assigned all via the ERP system. The component that XYZ is missing from its ERP system is its forecasted demand. Aside from any long-term VMI agreements, XYZ does not currently upload its forecasting knowledge to tis ERP system. Any forecasting insight is mentally planned for, but this method has its disadvantages. Mentally planning for future work without adding it to the existing load within an ERP system can be cumbersome. There are a lot of factors that can easily be forgotten, and the information can get overwhelming. Making decisions regarding increasing resource capacities via investments in new equipment and employees can become somewhat of a guessing game if management does not have visibility to expected future work in addition to existing work.

5.3 Proposed Improvements

From a bigger picture and longer-term point of view, implementing forecasted demand into existing workload could be beneficial for guiding sustainable growth. As a company begins to grow, it must expand its resource capacities to support the future increase in workload. Creating an aggregate future workload can provide increased justification for hiring more employees or investing in new equipment. A company may also investigate adding new capabilities its arsenal if a future demand is high enough. Without this insight, these decisions must be made based on judgment, which can be risky. Currently, XYZ primarily uses judgement and market insight to drive these growth decisions. While these investments have been extremely successful in the past, solidifying these decisions with an aggregate demand forecast can mitigate some of the risk. It can be expected that XYZ would be able to better level-load its resources and more safely invest in its growth if it is able to add forecasted work to existing work in its ERP system.

5.4 Validation

Forecasting and the ensuing implementation of these forecasts into an ERP system has a substantial impact to engineering managers. Department managers are typically responsible for staffing their respective department appropriately for the given workload. They must assess their resources and strategically allocate them to the various tasks at hand to unsure completion by the required dates. If they had insight to expected future demand, they would be better able to prepare their departments for this work. As previously mentioned, this could come in the form of offering overtime to get ahead of an anticipated spike in workload. If this spike were projected to last for a long time and become a routine workload, the manager could investigate hiring another employee to keep up. If done in advance, this employee may have time to be trained prior to the spike in workload. Anticipated lulls in workload may offer an engineering manager an opportunity to schedule training for some of their employees. Cross training between departments during lulls in workload is an excellent way to mitigate against future spikes as employees can assist in more areas when needed.

Executive-level engineering managers primarily focus on business strategy and growth. These individuals will be involved in the decision making of whether to invest in new equipment and capabilities. If future demand shows a consistent increase in turned product, the executives must investigate purchasing more lathes. If there appears to be a lot of potential work requiring a capability that is not currently done in-house, they may also investigate adding that capability to the company's arsenal. These investments are risky to the business because they require substantial capital but are necessary for company growth. Having the foundation of an aggregate future demand forecast will help mitigate the inherent risks of investment and provide insight to the worthy investments to make.

6. Conclusion

Capacity planning is a highly beneficial, but equally difficult exercise for contract manufacturing companies. Given that the manufacturer is typically in a reactionary position, it can often be a scramble to allocate the necessary resources required to accomplish tasks with the customer's timeframe. This reactionary position can result in drastic lulls and spikes in workload. An inconsistent workload will cause inefficiencies that negatively impact productivity, performance, and profitability. Preemptively allocating those resources to anticipated incoming tasks would allow a company to better level its workload.

Forecasting of incoming work can come directly from a customer. A customer-provided forecast is not always provided. However, when available, it can be assumed that the forecast is fairly accurate due to the customer's insight into projected product demand. A manufacturer may be able to devise its own forecast of incoming orders by reviewing order history of certain products. Especially when referring to products that have a substantial order history, routine purchasing frequencies, and low market demand volatility, patterns may be noticed. These patterns can be used to anticipate future customer orders. A salesperson may also be able to provide insight to future demand fluctuations based on their market intelligence and customer interactions. A vendor-managed inventory system can be implemented for high-demand products. This allows a manufacturer to strategically utilize its resources to meet future product demand. It can choose to maximize efficiency by reducing setups and teardowns, or level-load its resources by making the product during lulls in other work.

Once forecasts are devised, they must be effectively utilized. Adding anticipated workload to existing workload in an enterprise resource planning system is the most effective method of visualizing the expected resource demands. Engineering managers can then make decisions to strategically allocate these resources or invest in resource capacity expansion. Department managers can offer overtime or training sessions to account for spikes and loads in workload. New employees made be added to support a permanent increase in demand. Executive managers can mitigate the risks of investment in new equipment, resulting in sustainable company growth.

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Brian Merrill is a graduate student in the Management Department of the College of Engineering and Computer Science at Arkansas State and currently pursuing the Master's in Engineering Management. He is an Electro-Mechanical Engineer at a Pharmaceutical Manufacturing Facility located in North Las Vegas, Nevada. Holds a B.S., in Electrical Engineering from Nevada State College, with minors in Mechanical Engineering, and Biomedical Engineering and a certificate in Engineering Management from the universities engineering department.