FACTORS AFFECTING CAPACITY UTILIZATION IN TANZANIAN INDUSTRIES: HIERARCHICAL ANALYSIS

M.A.M. Victor

Department of Mechanical Engineering,
University of Dar es Salaam,
P.O. Box 35131, Dar es Salaam,
Tanzania

ABSTRACT

This paper provides a hierarchical analysis of the factors affecting capacity utilization in Tanzanian industries. Several factors were identified and sent to randomly selected industries in Tanzania for ranking. The collected data was summarized and analyzed. The analysis made use of a known procedure, the "Analytical Hierarchy Process" (AHP). The final results shows a ranking of the factors, on various hierarchical levels as to their percentage contribution in lowering the capacity utilization.

1. INTRODUCTION

It is a well known fact that Tanzanian industries are working under low capacity utilization. What it simply means here is that, an industry consisting of machinery/equipments, labour force and a system of inputs and outputs, is not realizing a possible higher output level. This output level is known as the production capacity.

Production capacity is the limiting capability of a productive unit to produce within a stated time, normally expressed in terms of output units per unit of time [1]. But capacity is an illusive concept, because it must be related to the intensiveness with which a facility is used. For example, it may be the policy to work a plant 6 days per week, one shift per day, producing a maximum of 2000 units per week. On this basis, one might rate the regular capacity as 2000 output units per week. But this limit can be increased by working overtime, resulting in a capacity limit with overtime of 2500 units. By adding a second shift, however, the capacity can be pushed to perhaps 3000 units per week.

Production capacity is the maximum rate of productive or conversion capability of an organization's operations [2]. Capacity incorporates the concept of rate of conversion within an operations setting. It is often difficult to get a realistic measure of capacity because of the day-to-day variations that are encountered. Employees are sometimes absent or late, equipment breakdowns occur, facility downtime is needed for maintenance and repair, machine setups are required for product changeovers, and vacations must be scheduled. Since all these uncertainties and variations cause "true" capacity to vary from time to time, they must all be considered in any estimate of capacity. You can see, then, that the capacity of a facility can rarely be measured in precise terms. Such measures as are used must be interpreted cautiously.

Production capacity is the maximum rate at which a system can accomplish work [3]. Consider two people washing and drying dishes after a banquet. The washer can wash 80 dishes per hour, and the dryer can dry 100 per hour. The system capacity of 80 per hour is determined by the "bottleneck" - the person washing the dishes. Obviously, the person drying the dishes will be idle fairly often while waiting for the washer.

From these definitions, it is evident that the question of capacity or in this particular case low capacity utilization has a lot of factors affecting it. It shows also how difficult it is to accurately say that a particular production system is utilized at a particular percentage. However, certain factors such as the machines, equipments, labour, inputs, outputs, and so on, have to be optimum if the highest level of capacity utilization is to be realized.

To improve the capacity utilization of a particular production system is synonymous with improving some or all of the factors affecting it. As these factors are many, one need to identify them and if possible to quantify their contribution to the overall problem. This is important because, resources, which will very likely be required in the improvement process, may not be sufficient to deal with all the factors at the same time. It is important, however to start by improving the parameters which will realize the maximum benefits, which will in turn increase the capability to deal with other factors.

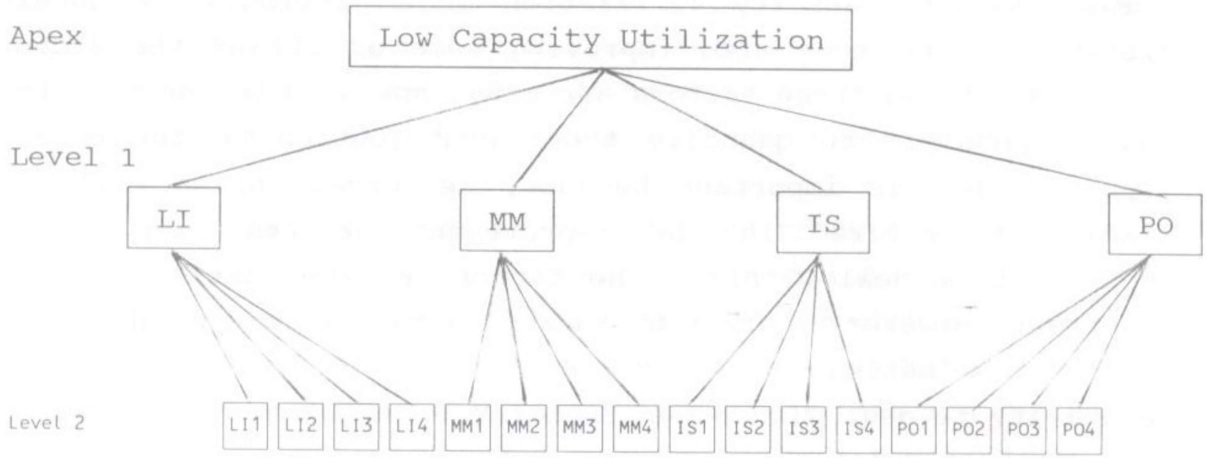
In this research paper, factors affecting capacity utilization in Tanzanian industries were identified. A questionnaire was prepared and sent to randomly selected industries, with the aim of quantifying the various identified factors as to their contribution to the low capacity utilization in their respective industries. The data collected was then compiled for all the industries and analyzed.

The analysis involved the grouping of factors hierarchically. The percentage contribution of factors in one lower level to a higher level in the hierarchy was established by using a methodology known as "Analytical Hierarchy Process" (AHP), [4].

2. THE FACTORS

The major factors contributing to the low capacity utilization in Tanzanian industries are hierarchically shown in Figure 1, and discussed below: It should be noted that the hierarchy levels have been suggested by the nature of the factors, and some variations could be accommodated.

(i) Labour inefficiency:
A normal human being, under normal conditions can perform a certain work at a certain optimum rate and thus provide an efficient



Legend:

LI = Labour Inefficiency

- LI1 = Lower salaries
- LI2 = Lower incentives
- LI3 = Smaller size of technical staff
- LI4 = Lower qualifications of technical staff

MM = Machinery and input Materials

- MM1 = Availability of local raw materials
- MM2 = Availability of imported raw materials
- MM3 = Availability of spare parts
- MM4 = Old nature of machinery

IS = Infrastructure Support

- IS1 = Transport problems
- IS2 = Water supply problems
- IS3 = Power supply problems
- IS4 = Fuel supply problems

PO = National/International Policies

- PO1 = Tax policies
- PO2 = Importation policies
- PO3 = Workers union
- PO4 = Foreign currency related policies

Figure 1. Hierarchical representation of the factors

labour. When the same or another human being, under the same conditions performs at a lower rate, for reasons which may not be clear, he or she provides an inefficient labour. When you have a number of these individuals in a system, the combined result is a lower capacity utilization in the system.

When an individual's basic needs are not satisfied because of lower salaries and/or lower or no incentives, this may lead to inefficiency. Another reason may be due to lower qualifications pertaining to the individuals' specific activity or it may be that the size of total work force in relation to the tasks is small, leading to overwork.

(ii) Machinery and input materials:
Machine down time due to poor maintenance or poor availability of spare parts or old nature of machinery contributes to lower capacity utilization. When the input materials which could be local or imported are not received at the right time, right amounts and quality, it implies that there will be delays, poor quality of products leading to rework or scrap, all of which will finally contribute to lower capacity utilization.

(iii) Infrastructure support:
Any production system is a subsystem within a bigger influential system. This bigger system provides the requirements which will enable the proper functioning of the subsystem. These requirements may include the transport infrastructure, water, power and fuel supplies. When there are problems within these requirements, they will be transmitted to the subsystem reducing the effectiveness of the subsystem resulting in the lowering of the capacity utilization. Transport problems, insufficient water supply, frequent power cuts and insufficient fuel supply are all very common problems in Tanzanian production systems.

(iv) National and/or international policies:
Some policies do have an impact, sometimes negative, on production systems. Some of the important ones include, high tax rates, bureaucracy involved in securing the foreign currency and importation procedures, and the influence of the workers' union on the production system.

3. DATA COLLECTION

The research was conducted through a questionnaire which was sent to a total of 26 randomly selected industries in Tanzania. Out of the 26 industries, 16 are in the public sector, while 10 are in the private sector. The questionnaires were filled by a senior official in those selected industries. The officials gave their responses to the selected factors as to their contribution in lowering the capacity. The scale of the contributions of each factor ranged from 1 for the largest contribution in lowering the capacity to 5 for no contribution in lowering the capacity.

The summary of the responses is given in Table 1. In this table, the total responses for each factor, and for each of the scale values of 1 to 5 is indicated. The average value for each of the 4 sub-groups of factors is given for all the four factors. This average value is calculated by multiplying the scale values by the total responses in each scale and dividing by 26, which is the total number of all responses in each sub-factor. The average value of each of the four main factors is also indicated.

4. ANALYSIS OF THE DATA

The results of the survey are analyzed by using a method known as Analytical Hierarchy Process (AHP). AHP can be defined [4], as the structuring of the functions of a system hierarchically and then measuring the impacts of the elements in the hierarchy.

Table 1. Summary of collected data

LI Factors	Responses					Average
	5	4	3	2	1	
LI1	7	5	5	7	2	3.30
LI2	6	6	4	6	4	3.15
LI3	10	2	4	7	3	3.35
LI4	6	4	7	6	3	3.15
Total	29	17	20	26	12	3.24

MM Factors	Responses					Average
	5	4	3	2	1	
MM1	7	5	6	5	3	3.31
MM2	5	1	5	6	9	2.50
MM3	1	3	4	15	3	2.39
MM4	7	4	4	5	6	3.04
Total	20	13	19	31	21	2.81

IS Factors	Responses					Average
	5	4	3	2	1	
IS1	7	6	8	4	1	3.54
IS2	12	5	4	5	0	3.92
IS3	4	7	4	8	3	2.77
IS4	12	7	1	6	0	3.96
Total	35	25	17	23	4	3.56

PO Factors	Responses					Average
	5	4	3	2	1	
PO1	5	3	9	7	2	3.08
PO2	2	2	3	10	9	2.15
PO3	16	5	3	2	0	4.35
PO4	2	0	2	8	14	1.76
Total	25	10	17	27	25	2.84

As previously mentioned, the factors contributing to lower capacity utilization in Tanzania industries have been grouped hierarchically as shown in Figure 1.

A hierarchy is a particular type of system, which is based on the assumptions that the entities, which have been identified, can be grouped into disjoint sets, with the entities of one group influencing the entities of only one other group, and being influenced by the entities of only one other group. In this case, the groups are called levels, they could also be called cluster or stratum. Level 1 contains the apex objective factor of the analysis, "Low capacity utilization". Level 2 contain the 4 factors contributing to the apex while level 3 contains factors contributing to each of the level 2 factors.

In practice there are no set procedures for generating the objectives, criteria and activities to be included in a hierarchy or even a more general system. It is a matter of what objectives we choose to decompose the complexity of that system. One attempts to keep in mind that the ultimate goals need to be identified at the top of the hierarchy; their sub-objectives immediately below, followed by actors, forces constraining them and then their policies. A valuable observation about the hierarchical approach to problem solving is that the functional representation of a system may differ from person to person.

Preference matrices

After having the hierarchy as shown in Figure 1, the second step is to determine the potency with which the various elements in one level influence the elements on the next higher level, so that we may compute the relative strengths of the impacts of the elements of the lowest level on the overall objective. We begin by finding the strength of importance on the level 2 elements with respect to level one, the apex objective. Then for each element in level 2, we determine the strength of importance of the level 3 elements.

How, then, do we determine the "strengths", or the priorities of the elements in one level relative to their importance for an element in the next level?. The most elementary aspect of the method is going to be used. An n x n matrix is formed as seen in Table 2, where n is the number of elements in a level under consideration. The matrix is known as Matrix of Preference. E1 .... En represent the elements of the level concerned, with subscripts i for column and j for rows. L shows the element over which the comparison is being made. The Aij values in the matrix are the strength measures obtained by a pair-wise comparison. For example, E_1 is A_{12} times as important as E_2. They are usually numerical values ranging from 0 to 9.

Table 3 gives the definition and explanation of the strength measures. The column with the title 'calculated ratio' is obtained from the collected data. Knowing that the response values range from 1 for the highest contribution to lower productivity, to 5 for no contribution to lower productivity, the possible ratios between factors range from 1/5 = 0.2 to 5/5 = 1. If the ratio between two factors is 0.2, it means one has an absolute importance over the other, hence a value of 9 in the intensity of importance. In this manner, the ratios between 0.2 to 1.0 are fitted on the scale of 9 to 1, that is the intensity of importance as shown in Table 3.

The collected data summarized in Table 1 is used to compute the calculated ratios and hence the intensity of importance. If you are comparing say LT1 and LT2, you will find from Table 1 that the average response for LT1 = 3.30 and that of LT2 = 3.15. Since the smaller the response value, the larger the contribution of that factor to its parent and subsequently to the apex, it will be true in this case that LI2 contributes more to the factor LI than LI1. To find the intensity of the importance, a ratio of the stronger factor to that of the weaker factor is found, in this case,

Table 2. Matrix of preference: General form

L	E_1	E_2	E_3	……	E_j	……	E_n
E_1	A_{11}	A_{12}	A_{13}	…..	A_{1j}	…..	A_{1n}
E_2	A_{21}	A_{22}	A_{23}	…..	A_{2j}	…..	A_{2n}
E_3	A_{31}	A_{32}	A_{33}	…..	A_{3j}	…..	A_{3n}
..	…	…	…	…..	…	…..	…
..	…	…	…	…..	…	…..	…
E_i	A_{i1}	A_{i2}	A_{i3}	…..	A_{ij}	…..	A_{in}
..	…	…	…	…..	…	…..	…
..	…	…	…	…..	…	…..	…
E_n	A_{n1}	A_{n2}	A_{n3}	…..	A_{nj}	…..	A_{nn}

Table 3. The strength measures

Intensity of Importance	Calculated Ratio	Definition	Explanation
1	1.0	Equal importance	Two activities contribute equally to the objective
2	0.99 - 0.91	Intermediate Value	When compromise is needed
3	0.90 - 0.81	Weak importance of one over the other	Experience and judgement slightly favors one activity over another
4	0.80 - 0.71	Intermediate Value	When compromise is needed
5	0.70 - 0.61	Essential/strong importance	Experience and judgement slightly favor one activity over another
6	0.60 - 0.51	Intermediate Value	When compromise is needed
7	0.50 - 0.41	Very strong or demonstrated importance	An activity is favored very strongly over another
8	0.40 - 0.31	Intermediate Value	When compromise is needed
9	0.30 - 0.20	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
0	-	No importance	Activity have nothing to do with the objective

3.15/3.30, which gives 0.95, as the calculated ratio. Using Table 2, this ratio will correspond to intensity of importance no. 2. This is repeated for all the possible comparisons to obtain the preference matrices as shown in Table 4. The average values for each of the four factors are similarly used to obtain the preference matrix for the apex, shown in the same Table 4.

Vector of priorities

The next step consists of the computation of a vector of priority from each of the performance matrices. There are a number of methods possible, but in this case the following method is used. Multiply the n elements in each row and take the nth root. Normalize the resulting numbers to get a column vector known as vector of priorities. These vectors are shown on Table 5.

5. ANALYSIS OF THE METHODOLOGY

The measure of accuracy of the values used in the strength measures is known as the consistency measure. In general, what it means is that when we have a basic amount of raw data, all other data can be logically deduced from it. In doing pair-wise comparison to relate in activities so that each one is represented in the data at least once, we need n-1 pair-wise comparison moments. From them, all other judgements can be deduced simply by using the following kind of information: if activity E_1 is 3 times more dominant than activity E_2, and 6 times more dominant than activity E_3, then $E_1 = 3E_2$ and $E_1 = 6E_3$. It should follow that $3E_2 = 6E_3$ or $E_2 = 2E_3$ also $E_3 = \frac{1}{2}E_2$. Use of any other number in the comparison of E_2 and E_3 will create inconsistency in the matrix.

This happens frequently and is not a disaster, and one of the reasons is, for most problems, that it is very difficult to identify n-1 judgements which relate all activities and of which one is absolutely certain. Under these conditions, it is however,

Table 4. Preference matrices

APEX	LI	MM	IS	PO
LI	1	1/3	2	1/3
MM	3	1	4	2
IS	1/2	1/4	1	1/4
PO	3	1/2	4	1

$\lambda max = 4.08$; C.I. = 0.03; C.R. = 0.03

LI	LI1	LI2	LI3	LI4
LI1	1	1/2	2	1/2
LI2	2	1	2	1
LI3	1/2	1/2	1	1/2
LI4	2	1	2	1

$\lambda max = 4.06$; C.I.=0.02; C.R.=0.02

MM	MM1	MM2	MM3	MM4
MM1	1	1/4	1/4	1/2
MM2	4	1	1/2	3
MM3	4	2	1	4
MM4	2	1/3	1/4	1

$\lambda max = 4.10$; C.I.=0.03; C.R.=0.03

IS	IS1	IS2	IS3	IS4
IS1	1	3	1/4	3
IS2	1/3	1	1/4	2
IS3	4	4	1	5
IS4	1/3	1/2	1/5	1

$\lambda max = 4.17$; C.I.=0.06; C.R.=0.06

PO	PO1	PO2	PO3	PO4
PO1	1	1/5	4	1/6
PO2	5	1	7	1/3
PO3	1/4	1/7	1	1/8
PO4	6	3	8	1

$\lambda max = 4.27$; C.I.=0.09; C.R.=0.10

Table 5. Priority Vectors

Apex =

LI	0.14
MM	0.45
IS	0.09
PO	0.32

LI =

LT1	0.20
LT2	0.33
LT3	0.14
LT4	0.33

MM =

MM1	0.09
MM2	0.34
MM3	0.43
MM4	0.14

IS =

IS1	0.23
IS2	0.12
IS3	0.57
IS4	0.08

PO =

PO1	0.10
PO2	0.30
PO3	0.04
PO4	0.56

important to be able to measure the departure from consistency.

Three parameters, maximum eigen value (λ_{max}), consistency index (C.I.) and consistency ratio (C.R.) are provided here for that measure. The following explanation shows how to obtain them and gives the reasonable values for each.

We multiply the matrix of preference by the priority column vector, (Table 5), to obtain a new column vector. If we divide the first component of this new vector by the first component of the priority vector, the second component of the new vector by the second component of the priority vector and so on, we obtain another vector. If we take the sum of the components of this vector and divide by the number of components in the vector we have an approximation to a number λ_{max} (called the maximum of principal eigen value) to use in estimating the consistency as reflected in the proportionality of preferences. The closer λ_{max} is to n (in an n x n matrix) the more consistent is the result.

Deviation from consistency, called consistency index (C.I.), may be represented by $(\lambda_{max}-n) / (n-1)$.

Consistency Ratio (C.R.) is the ratio of C.I. to the average R.I. for the same order matrix, where average R.I. is the average Random Index obtained from the C.I. of an experiment of randomly generated reciprocal matrix from the scale 1 to 9, with reciprocal forced. Table 6, shows the R.I. values for n = 1 to 15. A consistency ratio of 0.10 or less is considered acceptable. The values of λ_{max}, C.I. and C.R. are given below each of the preference matrices in Table 4.

6. ANAYSIS OF THE RESULTS

All the preference matrices given in Table 4 have a consistency ratio (C.R.) values less than 0.10, except one with 0.10, and they are generally considered acceptable as per consistency. Vectors of priority obtained by the method explained earlier are given in Table 5. The apex vector show the contribution of each of level one factors to the apex. The vectors LI, MM, IS, and PO shows contributions of level 2 factors to each of the four level 1 factors.

Essentially one could say that the priority vectors provide the percentage contribution of each of the factors to the ones above them in the hierarchy. This information is summarized in Table 7, where the percentage contribution of each factor, in lowering the capacity utilization in Tanzanian industries is indicated.

For example, results shows that, the highest contribution to the problem is from MM3- Availability of spare parts (19.4%), followed by PO4- Foreign currency related policies (17.9%), and so on to the least contribution from IS4- Fuel supply problems (0.7%).

These results do compare well with the real situation in the Tanzanian industries at the time of data collection. Spare parts availability, and foreign currency policies and availability were indeed the main problems affecting capacity utilization in Tanzanian industries.

7. CONCLUSION

The paper provides a methodology for the application of a very strong analysis tool, the "Analytical Hierarchy Process". This tool can be used in the analysis of various forms of data, as long as they follow some form of a hierarchical structure.

The results obtained from this analysis provides an important systems approach criterion, where a problem is broken down into sub-problems as a step towards solving it. With limited resources,

Table 6. Random Index (R.I) values

Order of the matrix (n)	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 7. The final percentage contribution of the factors

Factor	% Contribution
LI = Labour Inefficiency	**14.0**
LI1 = Lower Salaries	2.8
LI2 = Lower Incentives	4.6
LI3 = Smaller Size of Technical Staff	2.0
LI4 = Lower qualifications of Technical Staff	4.6
MM = Machinery and Input Materials	**45.0**
MM1 = Availability of Local Raw Materials	4.0
MM2 = Availability of Imported Raw Materials	15.3
MM3 = Availability of Spare Parts	19.4
MM4 = Old Nature of Machinery	6.3
IS = Infrastructure Support	**9.0**
IS1 = Transport Problems	2.1
IS2 = Water Supply Problems	1.1
IS3 = Power Supply Problems	5.1
IS4 = Fuel Supply Problems	0.7
PO = National/International Policies	**32.0**
PO1 = Tax Policies	3.2
PO2 = Importation Policies	9.6
PO3 = Workers Union	1.3
PO4 = Foreign Currency Related Policies	17.9

it will be necessary to solve any industrial problem in stages, and hence a need for the identification of the various stages. It is also important to start solving a problem with the parts which will realize the maximum benefits. In this case, if one intends to increase the capacity utilization at the national level, the results shows where to start, that is with the factors having highest contribution to the problem.

In conclusion, the following points should be noted:

(a) The collected data is subject to personal biases

(b) The sample industries, although randomly selected, may not be a true representative of all the Tanzanian industries.

(c) The factors analyzed were not exhaustive, other factors could be incorporated thus changing the percentage contributions.

(d) It is possible to apply the method to a single industry, and with proper collection of data, the results will be very valuable.

(d) When dealing with bigger volumes of data, it will be a good idea to write a computer program for the methodology.

REFERENCES

[1] E.S. Buffa, "Modern Production Operations Management", John Wiley & Sons, 1983.

[2] E.E. Adam Jr., and R.J. Ebert, "Production and Operations Management: Concepts, Models, and Behavior", Prentice - Hall, Inc.: Englewood Cliffs, N.J., 1978.

[3] D.W. McLeavey, and S.L. Narasimhan, "Production Planning and Inventory Control", Allyn and Bacon, Inc., 1985.

[4] T.L. Saaty, "The Analytical Hierarchy Process", McGrall-Hill, 1980.