8.0 SUMMARY CONCLUSIONS, FUTURE SCOPE AND LIMITATION:

Considering the present trend of investigation within a very narrow field of specialisation, the present search envelope quite a large area but the object was very clear and a specific one "To reveal some unknown facets of machined surface finish". The area of investigation extended beyond the narrow specialisation of metal cutting or machinability and tool life to such areas as metallurgy, optimisation and metrology. Such a work is bound to have some limitations, particularly when the work is done in an undergraduate department with not much modern facilities to work with. Considering that this is the first attempt on such a problem, there must have some scope for future work and improvements. In fact, no work can be said to be the "Last Work" and every research should inspire further research. The work that does not generate controversies, discussions and clarifications should not achieve full satisfaction of fulfilment.

8.1 SUMMARY CONCLUSIONS:

Though conclusions were drawn at the end of every chapters, it will be necessary to sum up them here in brief.

(a) The first part of investigation written in Chapter-3, provided a very powerful variability index as $R_{max}/R_a$ ratio.
It was observed that though theoretically $R_{\text{max}}/R_{\text{a}}$ ratio should be 4 or 5.28 if randomness is considered, the practical values of this ratio widely varied between 0.5 to 15. From this it was concluded that there are two distinctive zones and two categories of factors that operate on to effect the machined surface finish. At low feed range some factors operate that deteriorate the machined surface finish where as at high feed some other factors operate to improve the surface finish. Therefore all factors are not to be treated same. It is necessary to identify these factors and separate them as per their characteristics of deterioration and improvements. The $R_{\text{max}}/R_{\text{a}}$ ratio here is serving as a good index of variability.

(b) A clear distinction must be made between a surface finish generated and a surface finish obtained.

It is observed in Chapter 4.0, that some factors like side flow, micro-chatter and to some extent sponzipfil and built up edge will add up to deteriorate the ideal surface generated at low feed and low speed machining conditions. As there is a process capability of machine tool towards its tolerance or dimensional accuracy, there must be process capability of machine tool system towards "minimum roughness or maximum finish obtainable in it. These all depend on the factor just mentioned above.
On the other hand at high feed range, the improvement in surface finish is obtained due to some combined effect such as "Burnishing effect". Here, the operating factors are the radial force, nose radius, coefficient of nose friction and cutting speed. These factors together produce the effect of "Burnishing" which improves upon the theoretically expected surface. Thus the actual surface finish obtained is considerably finer than it is expected based only on geometrical analysis, wrt. the particular value of feed and nose radius. These variability factors are discussed in detail in Chapter 4.0.

(c) The fact that the different materials or even the different grades of the same material produce different surface finish under similar cutting conditions, was observed by various authors from time to time. However, no attempt was made to determine the internal mechanism responsible for such differential behaviour. The much needed metallurgical explanation was provided in Chapter 5.0.

The investigation was carried out to find out the effect of grain size and hardness of work material on the machined (turned) surface finish. Mainly aluminium was used for the present investigation. With the help of different annealing treatment grain size (both cross sectional and longitudinal) and hardness were altered to determine precisely each of their effects on surface finish while machined under identical as well as differing cutting conditions. Some valuable conclusions were drawn in Chapter 5.0. A few of them are also listed below.
(i) An already machined surface shows an improvement of 5 to 10% on heat treatment as shown in the trend of $\Delta R_1$ provided turning is done with very fine feed (upto 0.06mm/rev.). For higher feeds a slight deterioration in finish is observed.

(ii) As the grain sizes vary, 20 to 60% deviations ($\Delta R_2$) in surface finish on re-machining is observed. The deviation $\Delta R_2$ decreases as both the grain sizes increases and the feed is also increased. Further, machining with higher values of nose radius (0.8mm) and higher speed (34m/min) shows higher deviations. Unless the reduction in hardness is accompanied by significant increase in grain size, machinability does not improve and the deviation also remain high.

The effect of depth of cut and grain size is similar in nature as that of feed and grain size. However, for cutting speed as the speed is increased along with increase in grain size, deviation first decreases and then increases for higher grain sizes. This must be due to abusive machining.

(iii) For aluminium a nose radius of 0.4mm gives better finish than 0.8mm. Thus for better finish we must select the optimum tool geometry say nose radius depending on the grain size and hardness of the material.

(iv) Effect of hardness: The hardness as well as grain size do not have much effect on $\Delta R_1$. The annealing resulting in only marginal decrease in hardness and not much increase in grain size shows increase in deviation. However, a little more annealing ensures complete stress relief and best finish. But no such benefit in surface finish, in further decreasing
hardness where the surface finish deteriorated due to metal flow up due to softening. In addition to metallurgical aspect, other machining parameters were also involved in the investigation. Out of them, the effect of depth of cut and nose radius was detected and discussed. Though detail experiments were carried out for aluminium in turning, some short experiments on different grades of steel in grinding was also performed and behaviour reported in Chapter 5.0.

(d) Cost of surface finish was never determined in any research project so far. However, surface finish was considered in machining optimisation model as only one of the constraint. Two different optimisation models, one unconstrained and the other constrained model were presented in Chapter 6.0 and 7.0. Both are multivariable models, one solved by using geometric programming and the other by classical solution. By using these new techniques, originally developed here, it was possible to determine not only the minimum cost of surface finish but also all the optimum machining parameters like speed, feed, depth of cut and nose radius. The different characteristics of the cost behaviour with different parameters were also discussed in detail.

To sum up, the work, which is all original and first attempt, were arranged in sequence as

Chapter 3.0 - Variability index, Chapter 4.0 - Variability factors
Chapter 5.0 - Material factors, Chapter 7.0 and 8.0 - Cost factors.
8.2 FUTURE SCOPE AND LIMITATIONS

As already pointed out every research work and the theory forwarded should obviously generate controversies, discussions and clarifications, for full satisfaction and lively-ness of the subject. One has to work within the available resources, ability and time and leave some scope for others to continue the relay race.

It will be worth quoting Voltaire here "All generalisations are false, including this". Or that of Newton collecting only pebbles on the sea shore and yet a vast sea remaining unexplored. It is only that 'undone' thing that inspire others to work in the area. We should rather be satisfied if we have really contributed our "Delta X" to that vast ocean of knowledge - as my beloved teacher used to say.

It is not for criticism or finding loop holes in one's work but even the strong points need to be located and extended out as in the case of a multistoried buildings, the steel reinforcements of pillars are kept open out extended for future construction of upper stories. Keeping this thing in mind, some areas for future work is suggested here under.

(a) It is possible to investigate thoroughly, by experimentation and model building of such variability factors which were indicated in Chapter-4.0 like side flow, micro-chatter and
These three topics can generate huge amount of work theoretically and experimentally and are surprisingly not covered well till today.

(b) For material factors, there are other materials which may receive attention by future researchers, these are steel, cast iron, brass, bronze and others. Then there are other methods of machining in addition to turning for generating surface finish. Mainly grinding and milling may be considered for future investigation. Here for variability index and variability factors, only steel in turning was considered. For material factor the different grades of steel in cylindrical grinding was considered, cast iron came as a passing reference. More detail and extensive work was done on aluminium in turning. As there are innumerable number of metals and several processes—all of them need to be investigated thoroughly.

(c) Cost of surface finish—two models both deterministic are developed and presented here. However several other models can be built up—particularly those taking into consideration statistical variations, known as stochastic models. Regression, correlation and simulation techniques can be used at appropriate places.

As this was the first attempt only the basic models were developed and presented leaving scope for future extension and modification.

Let us hope that this is the beginning and not the end.