Chapter 6

CONCLUSION

This chapter concludes the presentation of this research with the following three sections. The first section summarizes the research effort of this thesis. The second section describes the major contribution of this research and concluding comments. Finally, the third section outlines some recommendations for future research.

6.1 SUMMARY

This research presents a methodology to measure and evaluate efficiency and effectiveness in a fuzzy environment using goal programming (GP) and data envelopment analysis (DEA). The resultant approach is called Fuzzy GoDEA. The Fuzzy GoDEA framework proposes to allow imprecise specification of aspiration levels for the goals of efficiency and effectiveness and the ability to assign relative importance to these goals. The methodology is developed employing elements of data envelopment analysis to measure efficiency and effectiveness, fuzzy set theory to model imprecision in the aspiration levels of the efficiency and effectiveness goals and goal programming to model the priorities for the goals. The Fuzzy GoDEA model and its variations are motivated by the work of Athanassopoulos (1995) and Girod (1996).

The Fuzzy GoDEA approach assumes certain *a priori* knowledge regarding the efficiency and effectiveness targets. To allow imprecision in the achievement of the efficiency goal it is assumed that the upper and lower bounds on for the observed input and output values are known. This knowledge provides an interval of satisfaction for the efficiency constraints. For the input case the upper bound denotes the risk-free scenario and for the output case the lower bound denotes the risk free scenario *i.e.,* a low amount of output production with a high consumption of inputs. Similarly, there exists

knowledge regarding the global input and output targets along with their respective upper and lower bounds. Therefore, each efficiency and effectiveness constraint has an interval in which it can be satisfied. Consequently, this implies a fuzzy scenario and thus, a membership function is associated with each fuzzy constraint. In this research the membership functions are defined linearly. The membership functions denote the degree of satisfaction of the constraints and, by definition, vary between zero and one. The closer the membership function is to one the greater is the degree of satisfaction of the constraint, with crisp satisfaction when the membership function is one and no satisfaction when the membership function is zero.

The relative importance of the efficiency and effectiveness goals is also captured in the Fuzzy GoDEA methodology. The efficiency and effectiveness goals can be considered to be equally important or one more important than the other. Also, a combination of crisp and fuzzy goals is incorporated in this research by allowing one of the efficiency or effectiveness goals to be crisp and the other fuzzy. The Fuzzy GoDEA model and its variations accommodate various scenarios in this context. A third constraint reflecting minimal operational viability for a subset of the DMUs and a subset of the inputs/outputs is offered as a modeling contribution in this research. This constraint requires the decision-maker to specify a proportion of the global target for a desired input/output that must be assigned to a specified DMU to maintain a viable production scenario. Thus proportion can be derived from historical knowledge about the process or production environment. However, the minimal operational viability constraint is not included in the application due to lack of suitable information.

The conceptual Fuzzy GoDEA model and the underlying theoretical concepts proposed in this research are applied to a real-life manufacturing system. The applied component of this research comprises the implementation of the Fuzzy GoDEA methodology to a newspaper preprint insertion packaging line developed by Girod (1996). This application was chosen for the following reason. Girod (1996) and Parlikar (1996) applied fuzzy radial and non-radial DEA models respectively to this application. Thus, there existed a set of fuzzy efficiency results as a reference point. Also, sufficient

information was available to generate the upper and lower bounds for the input and output data sets as well as the global input and output targets and their bounds. Girod's (1996) data is essentially maintained in this research. Accordingly, the packaging line is modeled as a manufacturer of packages (output) utilizing direct labor, rework, and raw material (inputs). The process involves inserting commercial preprints into the packages to obtain finished packages. A complexity factor is used to account for the complexity of the insertion process. The data represents a forty-eight week period where each week is equal to one day (as the particular packaging line under consideration functions once a week).

The Fuzzy GoDEA model and its variations are applied to the data to obtain efficiency and effectiveness results for different scenarios involving goal priorities and fuzzy and crisp constraints. Three data sets are constructed from Girod's (1996) original data to assess the impact of a line reorganization event that occurred approximately at the midway point in the study horizon. Accordingly, the data sets are production days 1-24, production days 25-48 and production days 1-48. The BCC input reducing efficiency scores are used for comparison of the efficiency results of the Fuzzy GoDEA models with conventional DEA analysis.

The results obtained from the Fuzzy GoDEA variations show consistency for the three data sets with real world events as reported by operational records as well as in the evaluation of a subset of efficient units with the BCC evaluation. Also, the fuzzy concepts employed accomplish the objective of allowing *near-efficient* BCC units as peers for inefficient units. In other words, the envelopment surface has characteristics of a *thick* frontier compared to the conventional crisp frontier. The interpretation of near-efficient BCC units, however, is open to subjectivity of the analyst. Depending on the overall BCC performance of the data set near efficient units may not necessarily achieve scores near 100%. For the effectiveness goal, the Fuzzy GoDEA approach quantifies the degree of satisfaction with respect to achievement of the global targets. Importantly, the fuzzy formulation in this research enables the decision-maker to view the simultaneous achievement of the efficiency and effectiveness goals for different scenarios. Finally, the

Fuzzy GoDEA model variations provide the decision-maker with a tool to assess efficiency and effectiveness performance under relaxed conditions for a specific scenario. This information can provide the decision-maker with valuable information regarding the operating characteristics of efficient and inefficient production days and the global performance of the packaging line.

6.2 RESEARCH CONTRIBUTION AND CONCLUDING COMMENTS

The Fuzzy GoDEA methodology developed in this research employs attractive features of fuzzy set theory, goal programming and data envelopment analysis. The fuzzy element allows imprecise aspiration levels for the efficiency and effectiveness goals when the decision-maker chooses to attain a *satisfycing* rather than *optimizing* approach. With respect to the efficiency goal, the Fuzzy GoDEA formulation allows relaxation of the DEA structure and also enables inefficient units to be compared with units that are evaluated by conventional DEA analysis as not only 100% efficient but also less than 100%. In reality, such comparisons hold value as it may be easier for inefficient units to achieve operating levels of units more efficient then them but not necessarily 100% efficient.

The fuzzy dimension of this research aims to accommodate imprecise aspiration levels and thus, inherently introduces subjectivity in the analysis and interpretation of the data and the results. The subjectivity component assumes presence in the choice of the membership function, the bounds on the inputs and outputs, the choice of the global targets, and the bounds on the global targets. In the analysis for the results, the decision-maker must use discretion regarding the definition of *near-efficient* units and the numerical value of the membership functions that denote the degree of satisfaction for the efficiency and effectiveness constraints. A linear membership function is employed in this research. Alternative forms of the membership function (exponential, triangular, etc.) could provide different results. The Fuzzy GoDEA framework is especially attractive when the decision-maker wishes to assign relative importance to the efficiency

and effectiveness goals as it does not require quantitative specification of the preferences for achievement of the goals. For the crisp efficiency and effectiveness constraints, a conventional goal programming approach with deviation variables is employed. The deviation variables provide the decision-maker with information regarding the under and over achievement of the goals.

6.3 RECOMMENDATIONS FOR FUTURE RESEARCH

The current research can be extended and further investigated with respect to one or more of its components, namely, fuzzy set theory, goal programming and data envelopment analysis.

With respect to fuzzy set theory, the suitability of the form of the membership function with respect to the data is an issue of interest. Further, the impact of the form of the membership function on the efficiency and effectiveness results also warrants attention. The physical interpretation of the membership functions for decision-making use constitutes an important part of the decision-making process and requires investigation. Also, formulations to incorporate vagueness in the input and output data as well as imprecision in the aspiration levels for the efficiency and effectiveness goals would be a next step in the realm of fuzzy DEA.

With respect to goal programming, formulations can be developed to model quantifiable preferences of the decision-maker regarding the relative importance of the goals. In the same context, mathematical methods to evaluate these preferences based on operations knowledge can be explored. The relative importance within the effectiveness goals (*i.e.*, relative importance for achievement of global targets between inputs and outputs) also offers research opportunities.

With respect to DEA, the notion of a thick frontier presents great interest in efficiency measurement. This, of course, is an issue that requires DEA to be explored in

conjunction with fuzzy set theory. The evaluation of fuzzy efficiency scores is another area of research that arises in efficiency measurement.

Finally, some general areas of interest are the construction of bounds for the input and output data, global targets and bounds on the global targets. The Fuzzy GoDEA approach can be tested with other applications and extended to incorporate multi-level hierarchical systems.