Studies on Advanced Modeling Techniques for Optimal Reservoir Operation and Performance Evaluation of an Irrigation System

THESIS
Submitted in partial fulfilment
of the requirements for the degree of
DOCTOR OF PHILOSOPHY

By

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Under the supervision of

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BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE
PILANI (RAJASTHAN)
2005

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PILANI (RAJASTHAN)

CERTIFICATE

This is to certify that the thesis entitled **"Studies on Advanced Modeling Techniques for Optimal Reservoir Operation and Performance Evaluation of an Irrigation System"** submitted by **Vasan A** ID. No. **2000PHXF409** for award of Ph.D. Degree of the Institute embodies the original work done by him under my supervision.

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ACKNOWLEDGEMENTS

I wish to express deep sense of gratitude and sincere thanks to my thesis supervisor Dr. K. Srinivasa Raju, Associate Professor, Civil Engineering Group for his valuable guidance, encouragement, suggestions, and moral support throughout the period of this research work. It has been a privilege for me to work under his valuable guidance.

Gratitude is also accorded to BITS, Pilani for providing all the necessary facilities to complete the research work. My special thanks to Prof. S. Venkateswaran, the Vice-Chancellor of the Institute for allowing me to pursue my research work successfully. My sincere thanks to Prof. L. K. Maheshwari – Pro Vice-Chancellor and Director, Prof. K. E. Raman - Deputy Director (Administration) and Prof. V. S. Rao - Deputy Director (Off-Campus Programmes) for providing the necessary infrastructure and other facilities. Special acknowledgements to Prof. A. K. Sarkar - Dean (Instruction Division and Faculty Division I) for his suggestions, valuable inputs and critical evaluation as a decision maker.

I also express my gratitude for the kind and affectionate enquiries about the work and the encouragement given by Prof. Ravi Prakash - Dean (Research and Consultancy Division).

Much appreciation is expressed to Prof. Rajiv Gupta, Prof. B. V. Babu and Dr. Ajit Pratap Singh who are the members of Doctoral Advisory Committee (DAC), for their kind suggestions, moral support and assistance.

Special acknowledgements to Chief Engineer of Mahi Bajaj Sagar Project Mr. Kundan Lal, Mr. S. C. Vashista (Executive Engineer), Mr. R. K. Bansal (Assistant Executive

Engineer), Mr. S. R. Verma (Senior Draftsmen), Mr. Dinesh Kumar Vajpayee (Junior Draftsmen) and other officials for providing necessary data in the form of reports, academic and practical discussions, motivation and encouragement for conducting the interviews and providing infrastructural support from time to time. Sincere acknowledgements to all the farmers' in the command area of Mahi Bajaj Sagar Project for their joyful help and support rendered throughout the period of my research work including significant and valuable inputs during interviews.

I am grateful to Dr. Rainer Storn (International Computer Science Institute, Berkeley, USA) for providing me the encouragement to apply Differential Evolution (DE) for high dimensional problems and providing me the literature for the same. I am also grateful to him to include my research paper in the homepage of Differential Evolution as a potential scientific application of DE. I am thankful to Prof. D. Nagesh Kumar (IISc, Bangalore) who provided valuable inputs including the mathematical modeling and support through out my research work and I am very much grateful for the same.

Acknowledgements are also due to Prof. K.K.S. Bhatia (NIH, Roorkee), Prof. P.P. Mujumdar (IISc, Bangalore), Prof. N.S. Raghuwanshi (IIT, Kharagpur), Prof. Lakshman Nandagiri (NIT, Surathkal), Prof. Arup Kumar Sharma (IIT, Guwahati), Prof. N.V. Umamahesh (NIT, Warangal), Prof. Rohit Goyal (MNIT, Jaipur), Dr. V. Jothi Prakash (NIT, Tiruchirappalli), Dr. N.V. Krishna Rao (Head, Crop inventory and drought assessment, NRSA, Hyderabad) and Dr. K.Palanisami (Director, Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore) for their support from time to time.

Special thanks and appreciation is extended to Prof. H.S.Moondra, Dr. Anshuman, Mr. Manish Kewalramani, Mr. Amarendra Kumar Sandra and other members of Civil Engineering Group for their valuable advice and moral support throughout the study. I also thank to Mr. Devender Dabbas and Mr. Ramachandran who helped me during my research work for data collection and interviews in Banswara. I sincerely thank Prof. Meera Banerjee for peered review of the thesis. I am very grateful for the same.

I express my thanks to Mr. P. K. Mishra, Mr. Shiv Ratan Sharma, Mr. Suresh Saini, Mr. Shivpal Saini of Civil Engineering Group for their cooperation during the preparation of this thesis. I also wish to acknowledge Mr. Jamunadhar Saini, Mr. Mathuram Jangir, Mr. Ashok Saini, Mr. Mahavir Singh, Mr. Gopi Ram, Mr. Dalbag Singh, Mr. Babulal Saini and other members of Instruction Division for their help and cooperation.

I would like to thank members of Reprography, Xerox and Printing Sections for their prompt services. I would like to thank one and all who have helped me in myriad ways throughout the course of this work.

Acknowledgements to Ms. N.B. Radhika, Ms. Divya Ramakrishnan, Ms. P.B. Meenakshi, Mr. Swaminathan, Mr. Anand Kumar, Mr. Shankar and Mr. Anand Rathi who have given me joyful support.

Last but not the least, this work would not have been completed without the moral support I got from my parents Mr. S. Arunachalam and Mrs. A. Gandimadhi. My heartful thanks to my sisters Mrs. A. Poonguzhali, Ms. A. Devi, to my brother-in-laws Mr. K. Madhavan, Mr. P. Muthukumar and to my niece Ms. Harshitha who have given me moral support throughout the period of my research work.

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ABSTRACT

Irrigation systems in developing countries are facing tremendous pressure due to the ever increasing growth of population which necessitates enormous food production. This pressure demands significant improvements in the performance of irrigation systems. Accelerating competition for water from municipal and industrial sectors is also making the situation more complex. This necessitates a new irrigation management paradigm based on scientific methodology. The methodologies so developed are applied to an existing Mahi Bajaj Sagar Project (MBSP), Rajasthan, India that can serve as a model for further improvements.

The present investigation consists of two parts. Part 1 of the study is related to the formulation of an optimization model to evolve a suitable optimum cropping pattern and optimal reservoir operation that yields maximum annual net benefits. The irrigation planning model is solved using non-traditional optimization techniques, namely, Real-coded Genetic Algorithm (RGA), Differential Evolution (DE), Simulated Annealing (SA) and Simulated Quenching (SQ) and the results obtained are compared with Linear Programming (LP) for two scenarios. Extensive sensitivity analysis has been carried out in various techniques.

Part 2 of the study is related to performance evaluation studies of the sixteen irrigation subsystems. Seven performance criteria, namely, land development works, timely supply of inputs, conjunctive use of water resources, participation of farmers', economic impact, crop productivity and environmental conservation are considered for evaluation. Weights of the criteria are obtained by Analytic Hierarchy Process. Results of Kohonen Artificial Neural Networks (KANN) methodology for classification of irrigation subsystems is also discussed in detail. Three Multicriterion Decision Making (MCDM) techniques, namely, Multicriterion Q-Analysis-2 (MCQA-2), Multi Attribute Utility Theory (MAUT) and Compromise Programming (CP) are employed to rank the irrigation subsystems. The ranking pattern obtained by each of these three MCDM techniques is compared. Spearman Rank Correlation technique is used to analyze the correlation. Extensive sensitivity analysis is performed for KANN and MCDM techniques. The conclusions emanated from the study can be followed by project authorities for adoption and possible improvement.

Keywords: Analytic Hierarchy Process, Compromise Programming, Differential Evolution, Irrigation Planning, Kohonen Artificial Neural Networks, Linear Programming, Multi Attribute Utility Theory, Multicriterion Decision Making, Multicriterion Q-Analysis-2, Optimization, Performance Evaluation, Real-coded Genetic Algorithm, Reservoir Operation, Simulated Annealing, Simulated Quenching, Spearman Rank Correlation, Mahi Bajaj Sagar Project.

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A	=	(m x n) matrix of known constants
A^*	=	Lottery (Possibility)
A'	=	Number of alternatives
$A'_{C'}$	=	Neighborhood function centered on the winning neuron C'
A_i	=	Area of crop i grown in the command area (ha)
$AMAX_i$	=	Maximum area target of crop of index i (ha)
$AMIN_i$	=	Minimum area target of crop of index i (ha)
best	=	Best vector
bin	=	Binomial crossover (employed in DE)
B	=	(m x 1) vector of constants
B^*	=	Lottery (Possibility)
B_i	=	Net Return from i^{th} crop excluding ground water cost (Rs/ha);
BEN	=	Annual net benefits from the whole planning region (Rs)
C	=	(n x 1) vector of known constants
C'	=	Winning neuron
C_1 to C_7	=	Seven performance criteria
$C_{5\ best}$	=	Best value of C_5
$C_{5\ worst}$	=	Worst value of C_5
$C_{6\ best}$	=	Best value of C_6
$C_{6\ worst}$	=	Worst value of C_6
C_R	=	Consistency ratio
CCA	=	Culturable command area (ha)
CCA_B	=	Culturable command area under Bhungra canal (ha)

CCA_L	=	Culturable command area under Left Main canal (ha)
CCA_R	=	Culturable command area under Right Main canal (ha)
CCB	=	Maximum canal capacity of Bhungra canal (Mm^3)
CCL	=	Maximum canal capacity of Left Main canal (Mm^3)
CCR	=	Maximum canal capacity of Right Main canal (Mm^3)
CI	=	Consistency index
CoR	=	Cooling rate (employed in SA)
CoR''	=	Cooling rate (employed in SQ)
CPR	=	Crop productivity
CR	=	Crossover constant (employed in DE)
CUW	=	Conjunctive use of water resources
CWR_{it}	=	Crop diversion requirements per hectare of crop i in a month t (meters)
D	=	Dimensional parameter vector
D_a	=	Difference between ranks U_a and V_a achieved by the same alternative a
D_j	=	Euclidean distance between its weight vector w_j and input vector R
DE1-DE10	=	Ten DE strategies
exp	=	Exponential crossover (employed in DE)
E	=	Energy of the system
$E(t')$	=	Energy of the system at iteration t'
EC	=	Environmental conservation
EI	=	Economic impact
ET_c	=	Crop evapotranspiration (mm/month)
ET_o	=	Reference evapotranspiration (mm/month)
EV_t	=	Monthly evaporation loss for the month t (Mm^3)
f_j^*	=	Ideal value of criterion j
$f(a)$	=	Value of criterion j for alternative a
$f(x(t'))$	=	Function value at iteration t'

F	=	Weighting factor (employed in DE)
G1-G8	=	Number of groups after classification
GW_t	=	Monthly ground water withdrawal (Mm^3)
H	=	Average head of Power House 1
i	=	Crop index; i=1 to 36
I	=	Unit matrix
I_t	=	Monthly inflows into the reservoir for month t (Mm^3)
$I_t^{\alpha'}$	=	Dependable inflow value at level α'
IDB_t	=	Irrigation demands for Bhungra canal for the month t (Mm^3)
IDL_t	=	Irrigation demands for Left Main canal for the month t (Mm^3)
IDR_t	=	Irrigation demands for Right Main canal for the month t (Mm^3)
IS1 to IS16	=	Irrigation subsystems
j	=	Output neuron
k	=	Overall scaling constant
k_b	=	Boltzmann constant
k_c	=	Crop coefficient
k_j	=	Scaling constant for attribute j
$L_p(a)$	=	L_p - metric for alternative a
LDW	=	Land development works
LS	=	Live storage of the reservoir (Mm^3)
m_j	=	Minimum value of criterion j in set A
M	=	Number of neurons in input layer
M_j	=	Maximum value of criterion j in set A
MUT	=	Mutation probability (employed in RGA)
N	=	Number of neurons in the output layer
N'	=	Size of pairwise comparison matrix
NET	=	Function for creating new competitive layer in MATLAB
NEWC	=	Function of NET in MATLAB
NI	=	Number of iterations (employed in SA)

NI'' = Number of iterations (employed in SQ)

NP = Population size (employed in DE)

p = Parameter reflecting the attitude of the decision maker (employed in MCQA-2 and CP)

p' = Probability (employed in MAUT)

p_{ki} = Percentage cropping intensity for each crop i in Kharif season

p_{ri} = Percentage cropping intensity for each crop i in Rabi season

P = Power produced (Watts)

P_{GW} = Ground water cost (Rs/Mm^3)

$P(E)$ = Probability distribution of the system of energy E

$P(E(t'+1))$ = Probability distribution of the system of energy E at iteration $(t'+1)$

$PCI(a)$ = Project concordance index for alternative a

PCIMAX = Maximum expected values of PCI

$PCIN(a)$ = Normalized values of PCI for alternative a

$PDI(a)$ = Project discordance index for alternative a

PDIMAX = Maximum expected values of PCI

$PDIN(a)$ = Normalized values of PDI for alternative a

PF = Participation of farmers'

$PH1_t$ = Water requirement for Power House 1 for the month t (Mm^3)

$PH2_t$ = Water requirement for Power House 2 for the month t (Mm^3)

POP = Population size (employed in RGA)

$PSI(a)$ = Project satisfaction index for alternative a

PSIMAX = Maximum expected values of PCI

$PSIN(a)$ = Normalized values of PSI for alternative a

q = Connectivity level

$q_{\max}(a,s')$ = Highest q-level of alternative a for the incidence matrix $T(s')$

$\tilde{q}_{\max}(a,s')$ = Highest q-level of alternative a for the incidence matrix $\tilde{T}(s')$

$q_{\min}(a,s')$	=	Level at which alternative a is for the first time in the same equivalence class as another alternative for the incidence matrix $T(s')$
$\widetilde{q}_{\min}(a,s')$	=	Level at which alternative a is for the first time in the same equivalence class as another alternative for the incidence matrix $\widetilde{T}(s')$
Q	=	Discharge (cumecs)
rand	=	Random Vector
R	=	Spearman rank correlation coefficient
RI	=	Random index
s'	=	Total number of slicing levels ($s' = 1,2,....S$)
S_{t+1}	=	Reservoir storage volume at the end of month t or at the beginning of month $(t+1)$ (Mm^3)
S1, .., T1, ..	=	Scenario representations in sensitivity analysis
SIM	=	Function for simulating the network in MATLAB
t	=	Time index (1,2,.....12)
$t(a,j)$	=	Element of incidence matrix for alternative a and criteria j at $\alpha(s)$
tr	=	Transpose operator
T	=	Initial temperature (employed in SA)
T''	=	Initial temperature (employed in SQ)
$T(s')$	=	Incidence matrix at slicing level $\alpha(s')$
$\widetilde{T}(s')$	=	Complimentary incidence matrix at slicing level $\alpha(s')$
TGW	=	Annual ground water potential of the aquifer (Mm^3)
TRAIN	=	Function of NET in MATLAB
TSI	=	Timely supply of inputs
$u(.)$	=	Overall utility function operator
$u_j(.)$	=	Utility function operator for each attribute j
$u'(a,j)$	=	Element of preference matrix for alternative a and criteria j
U'	=	Preference matrix
U_a, V_a	=	Ranks achieved by two different MCDM techniques for the same alternative a

U_{best} = Utility of best value

U_{worst} = Utility of worst value

$USMP_t$ = Upstream requirement of water to Madhya Pradesh for the month t (Mm^3)

$V(a,s')$ = Sum of the weights corresponding to the criteria for each alternative a satisfied at level s'

w_j = Weight vector (employed in KANN)

w'_j = Weight of the criterion j (employed in CP)

$w_j(n)$ = Weight vector of j^{th} output neuron at time n

w_{ji} = Weight vector connecting output neuron to input neuron

$WR1_t$ = Minimum monthly releases for hydropower production in Power House 1 for the month t (Mm^3)

$WR2_t$ = Minimum monthly releases for hydropower production in Power House 2 for the month t (Mm^3)

$x_1, x_2, \ldots x_j$ = List of attributes (employed in MAUT)

$x(t')$ = A point in the system at iteration t'

X = (n x 1) vector of decision variables

X' = Input vector (employed in KANN)

X_c' = Random vector

X_t = Trial vector

X_a, X_b, X_c = Randomly chosen vectors

XR = Crossover probability (employed in RGA)

Z = Objective function

ΔE = Change in energy value between two successive iterations

$\Delta q(a,s')$ = Difference between $q_{\max}$ and $q_{\min}$ for the incidence matrix $T(s')$

$\Delta \tilde{q}(a,s')$ = Difference between $\tilde{q}_{\max}$ and $\tilde{q}_{\min}$ for the incidence matrix $\tilde{T}(s')$

$\lambda_{\max}$ = Maximum eigen value

α'	=	Dependability level
$\alpha(s')$	=	Slicing levels
$\eta(n)$	=	Learning rate parameter (employed in KANN)
γ	=	Unit weight of water (N/m^3)

ABBREVIATIONS/ ACRONYMS

AHP	=	Analytic Hierarchy Process
ANN	=	Artificial Neural Network
ART-II	=	Adaptive Resonance Theory Type-II
BC	=	Bhungra Canal
CP	=	Compromise Programming
CPU	=	Central Processing Unit
DE	=	Differential Evolution
FAO	=	Food and Agriculture Organization
GA	=	Genetic Algorithm
K	=	Kharif season
KANN	=	Kohonen Artificial Neural Networks
LINDO	=	Linear, INteractive and Discrete Optimizer
LMC	=	Left Main Canal
LP	=	Linear Programming
MATLAB	=	MATrix LABoratory
MAUT	=	Multi Attribute Utility Theory
MBSP	=	Mahi Bajaj Sagar Project
MCDM	=	Multicriterion Decision Making
MCQA-2	=	Multicriterion Q-Analysis-2
PH 1	=	Power House 1
PH 2	=	Power House 2
R	=	Rabi season
RGA	=	Real-coded Genetic Algorithm
RMC	=	Right Main Canal
SA	=	Simulated Annealing
SBX	=	Simulated Binary Crossover
SRC	=	Spearman Rank Correlation
SQ	=	Simulated Quenching

CHAPTER 1

INTRODUCTION

Irrigation systems in developing countries are facing significant pressure due to the ever-increasing growth of population which necessitates enormous food production, accelerating competition for water from municipal and industrial sectors. This necessitates a new irrigation management paradigm based on scientific methodology (Kirpich *et al*, 1999; English *et al*, 2002).

Pike (1995) explained the role of irrigation in India in expanding crop production, reducing output instability and providing protection against periodic drought and stressed the need of increasing the productivity per unit of water. He emphasized that over 55% of agricultural output is from irrigated lands and production from rain-fed areas is faced with lack of land for expansion and the prevailing risk of drought (Cancelliere *et al*, 1998). He opined that the choice lies between conventional planning based on heuristics, or a widespread reform and renewal of irrigation planning and management practices as food production in India will become increasingly dependent upon irrigation. Wichelns (2004) felt that the rate at which improvements in water management implemented by irrigators around the world might be enhanced substantially by replacing inappropriate policies with those that motivate farmers and others to use scarce resources efficiently (Karamouz *et al*, 2004).

There are many possible improvements that can be implemented in the irrigation management. Some of them are:

1) Optimum cropping pattern and reservoir operating policy that will yield optimum net benefits;
2) Conjunctive use of surface and ground water to tackle spatial and temporal variation of resources; and
3) Assessment of overall performance of the irrigation subsystems in an irrigation system (command area) so that the irrigation subsystem that is performing satisfactorily can be made a pilot system. This enables formulation of guidelines so that the efficiency and performance of the other irrigation subsystems can be improved based on pilot subsystem(s).

Based on the above mentioned possible improvements in the management of irrigation systems, the objectives of the present study are formulated. The first two of these possible improvements formed the basis for the case study of irrigation planning. The study integrates reservoir, canal and command area considerations keeping in view conjunctive use of surface and ground water resources. This will yield optimum annual net benefits and corresponding cropping pattern and reservoir operating policies. Mathematical modeling techniques that are applied are Real-coded Genetic Algorithms (RGA), Differential Evolution (DE), Simulated Annealing (SA), Simulated Quenching (SQ) and resulting solution is compared with that of Linear Programming (LP).

The third improvement formed the basis for the methodology of performance evaluation of an irrigation system. Various irrigation subsystems are analyzed by considering seven evaluation criteria, namely, land development works, timely supply of inputs, conjunctive use of water resources, participation of farmers, economic impact, crop productivity and environmental conservation (Raju and Duckstein, 2002). Irrigation subsystems versus evaluation criteria matrix is formulated based on the views of the farmers. Perception of the analyst (researcher), an outcome of the discussions with project officials at various levels, interactions with farmers and interviews with them using a structured questionnaire and available project reports is also considered. Satisfactorily performing irrigation subsystem is chosen using Artificial Neural Networks classification and Multicriterion Decision Making (MCDM) techniques.

The case study considered for the application of the two proposed methodologies is a major irrigation project Mahi Bajaj Sagar Project (MBSP), Rajasthan, India.

The thesis comprises seven chapters.

Chapter 1 gives the introduction to the study undertaken, brief description and organization of various chapters.

Chapter 2 presents a brief review of the literature pertinent to the study in

1) Optimal reservoir operation for irrigation planning
2) Irrigation system performance
3) Classification aspects of Artificial Neural Networks
4) Weighting of criteria
5) Correlation coefficient

The chapter concludes with the limitations of the previous investigations and the need for further research relating to irrigation planning, performance evaluation and related aspects.

Chapter 3 presents an overview of the MBSP planning environment and the command area considerations. This includes physical setting, cropping pattern, geology, climate and ground water status. An overview of socio-economic problems and constraints in utilizing the resources in the command area is also presented. The summary of the responses of interviews conducted involving farmers is also discussed in detail.

Chapter 4 presents the formulation of the mathematical model for irrigation planning with the objective of maximization of annual net benefits. The model is subjected to continuity equation, land availability, crop diversification considerations, upstream and downstream requirements, evaporation losses, surface and ground water availability, limitations on reservoir and canal capacities. Methodologies of different optimization techniques employed for the planning problem, namely, LP (traditional category), RGA, DE, SA and SQ (non-traditional category) are also presented. Comparative analysis of above solution methodologies is also presented. Results are presented in Part 1 of Chapter 6.

Chapter 4 also describes the necessity of performance evaluation and criteria that are required for comparing various irrigation subsystems. Description of classification technique, namely, Kohonen Artificial Neural Networks (KANN) for grouping irrigation subsystems is also explained. Three MCDM techniques, namely, Multicriterion Q-Analysis-2 (MCQA-2), Multi Attribute Utility Theory (MAUT) and Compromise Programming (CP) that are useful to rank the grouped irrigation subsystems (obtained after classification by KANN) are also described in detail. Brief description of Analytic Hierarchy Process (AHP) and Spearman Rank Correlation (SRC) technique which are used to compute weightage of performance criteria and correlation coefficients respectively are also presented. Results of AHP are presented in Chapter 5 whereas results obtained by other techniques are presented in Part 2 of Chapter 6.

Chapter 5 emphasizes the estimation of some of the parameters required in the above two methodologies. These are discussed in eight sections comprising

1) Estimation of crop diversion requirements ,
2) Monthly inflows into the reservoir,
3) Evaporation losses from the reservoir,
4) Upstream and downstream requirements,
5) Hydropower requirements,
6) Gross and net returns from the crops,
7) Weightage of various performance criteria and
8) Formulation of payoff matrix for performance evaluation scenario.

Chapter 6 presents the results and discussion in two parts of the case study. Part 1 of Chapter 6 is related to the irrigation planning methodology. It includes results of the planning model obtained by RGA, DE, SA, SQ and comparison made with LP.

Comparative analysis of results obtained by above optimization models are analyzed with respect to annual net benefits, cropping pattern, reservoir operating, release and ground water pumping policies. Extensive sensitivity analysis is also performed to ascertain the effect of various parameters employed in the above techniques.

Part 2 of Chapter 6 is related to methodology of performance evaluation studies of the sixteen irrigation subsystems. Seven performance criteria, namely, land development works, timely supply of inputs, conjunctive use of water resources, participation of farmers, economic impact, crop productivity and environmental conservation are considered. Results of KANN methodology for classification of irrigation subsystems is also discussed in detail. Three MCDM techniques, namely, MCQA-2, MAUT and CP are employed to rank the irrigation subsystems. Ranking pattern obtained by three MCDM techniques is compared. SRC technique is used to compute the correlation coefficient values between the three MCDM techniques. Extensive sensitivity analysis is also performed for KANN and MCDM techniques.

Chapter 7 presents the conclusions obtained from the above studies.

Contributions from the study, scope for further work, publications from the study and references are included in the thesis. Farmers' response survey questionnaire, summarized response survey analysis of each irrigation subsystem, pseudo code and flow chart of the non-traditional optimization techniques, flow chart for various MCDM techniques and sample calculation of MCDM and SRC techniques are included in Appendices A, B, C, D and E respectively.

The next chapter presents the review of literature related to reservoir operation for irrigation planning, performance evaluation, limitation and need for further investigations.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

For the purpose of planning and management of water resources, systems analysis techniques are being increasingly and extensively used for the last few decades. Potential applications of systems analysis are discussed by Loucks *et al* (1981), Chaturvedi (1992), Hall (1999), Stephens and Hess (1999) and Mayer *et al* (1999). In many of these applications, single and multiple objectives are used to define a planning problem. A number of techniques are available to solve single objective water resources planning problems, namely, Linear Programming, Nonlinear Programming, etc. But some more advanced techniques namely, Genetic Algorithms, Differential Evolution, Simulated Annealing and Simulated Quenching are also available which requires further investigations for their applicability in irrigation planning.

Similarly Multicriterion Decision Making (MCDM) techniques which are the outcome of multi-objective methodologies are also gaining importance these days. Some of the MCDM techniques that got prominence are ELECTRE-3, PROMETHEE-2, Compromise Programming, Analytic Hierarchy Process, Multicriterion Q-Analysis-2, Multi Attribute Utility Theory etc. More details about MCDM techniques are available in Pomerol and Romero (2000).

The important literature pertaining to the techniques that are relevant to the present studies are presented briefly in the following sections with relevance to optimal reservoir operation for irrigation planning aspects (single objective scenario) and performance evaluation aspects.

2.2 OPTIMAL RESERVOIR OPERATION FOR IRRIGATION PLANNING

Innovations are needed in both the technological and policy dimensions of water resource management to achieve the gains in productivity required to feed the world's increasing population (Frederiksen, 1996; Wichelns, 2004). The growing demand for water necessitated efficient utilization in the irrigation sector. In many countries, efforts to raise levels of agricultural production led to a greater dependence on irrigation. This pressure has been most severe in developing countries where water resources are often scarce and many irrigation systems are primitive (Bouwer, 2002). To meet the requirements, mathematical models and irrigation management methodologies are to be developed and integrated in command area planning scenario. Some of the important studies carried out so far are discussed briefly below.

2.2.1 Linear Programming

Linear Programming (LP) is an optimization technique applicable for the solution of problems in which the objective function and constraints appear as linear function of the decision variables (Rao, 2003). Brief literature review related to LP in irrigation planning context is as follows:

Lakshminarayana and Rajagopalan (1977) used LP model for maximizing the irrigation benefits for the case study of Bari Doab Basin in Northern India. Sensitivity analysis on the tube well capacity, the area available for irrigation, the operation costs for canals and tube wells were also carried out. Maji and Heady (1980) developed an optimal cropping pattern and reservoir operation policy for the Mayurakshi irrigation project, India, with the objective of maximizing the net benefits by considering the average and chance constrained inflows. Loucks *et al* (1981) discussed in detail the micro-level irrigation planning with a detailed example. Paudyal and Gupta (1990) solved a complex problem of irrigation management in Tinao river basin, Nepal, by LP. Various alternative activities, such as surface water diversion and pumpage, ground water withdrawal and recharge and alternative future operational scenarios were also analyzed.

Abdulkadri and Ajibefun (1998) applied LP model for generating farm plans for National Directorate of Employment farmers in eleven local government areas, namely, Akure, Ondo, Ikare, Owo, Ose, Ido-osi and Irepodun/Ifelodun, Ikole, Oye, Ekiti East and Akoko in Ondo state, Nigeria. They assessed the resource-use efficiency of the sampled farmers, and provided alternative farm plans that are nearly optimal. They suggested sole cropping as the optimal cropping system for the eleven areas. Singh *et al* (2001) formulated a LP model to suggest the optimal cropping pattern that provides maximum net return at different water availability levels for a case study of Shahi distributory situated at the tail end of the Richha branch in Sharda canal command, Uttar Pradesh, India. Doppler *et al* (2002) applied LP model for a case study of Jordan Valley. They concluded that optimizing cropping patterns and the allocation of irrigation water has increased the financial return from agriculture. Sethi *et al* (2002) developed groundwater balance model and LP model to determine optimum cropping pattern and groundwater allocation from private and government tube wells for a case study of a portion of coastal river basin in Orissa State, India. They concluded that the LP model was found to be an effective tool for land and water resources allocation and advised the state agencies and farmers to practice conjunctive use of river water and ground water so as to restrict further depletion of ground water level.

Similar studies are also reported by Khepar and Chaturvedi (1982), Chaturvedi and Chaube (1985), Morales *et al* (1987), Mayya and Prasad (1989), Thandaverswara *et al* (1992), Carvallo *et al* (1998), Garg and Ali (1999), Sahoo *et al* (2001), Tu *et al* (2003), Benli and Kodal (2003) where applications of LP are analyzed in detail.

2.2.2 Genetic Algorithms

Genetic Algorithms (GA) are search and optimization procedures that are motivated by the principles of natural genetics and natural selection. They combine the concept of the survival of fittest with genetic operators extracted from nature to form a robust search mechanism. Brief literature review of GA is as follows:

Chang and Chen (1998) applied real-coded and binary-coded algorithms for the case study of a flood control reservoir model. It is concluded that both variations of Genetic Algorithms are more efficient and robust than the random search technique. It is also observed that real-coded GA performs better in terms of efficiency and precision than the binary-coded GA. Wardlaw and Sharif (1999) evaluated several alternative formulations of a GA for the four-reservoir, deterministic and finite-horizon problem. They concluded that real-value coding, tournament selection, uniform crossover and modified uniform mutation are suitable for the planning problem. It is also concluded that real-value coding operates significantly faster than binary coding and produces better results. In addition, a nonlinear four-reservoir problem and ten-reservoir problem are also considered with previously published results. They concluded that GA approach is robust and is easily applied to complex systems. Similar studies are reported by Sharif and Wardlaw (2000), Wardlaw and Bhaktikul (2004).

Kuo *et al* (2000) developed on-farm irrigation scheduling and the GA optimization model in irrigation project planning with the objective of optimizing economic profits. The model is applied to an irrigation project, namely, Wilson canal system, located in Delta, Utah. Culturable command area of the project is 394.6 ha. Two other optimization techniques, namely, Simulated Annealing (SA) and iterative improvement techniques are also used and results are compared with those of GA. It was concluded that GA and SA consistently obtained the near optimal values whereas iterative improvement technique occasionally find the local optimum values.

Mardle and Pascoe (2000) emphasized the basic features, advantages and disadvantages of the use of the evolutionary techniques, specifically GA. Ranjithan (2005) stressed on the role of evolutionary computation in environmental, water resources systems analysis and discussed the various techniques in brief, namely, Simulated Annealing, Tabu Search, Genetic Algorithms, Evolutionary Strategies, Particle Swarm technique and Ant

Colony Optimization. He concluded that new areas that shape the direction of a beneficial integration of evolutionary computation into environmental and water resources systems are essential. Similar analysis is reported by Mayer *et al* (1999) and Mayer *et al* (2001).

Raju and Nagesh Kumar (2004) applied binary coded GA for irrigation planning to a case study of Sri Ram Sagar Project, Andhra Pradesh, India. Culturable command area of the project under modeling is 1,78,100 ha. They used linear objective function and constraints in the mathematical model. The GA technique is used to derive cropping pattern, reservoir operating policy that yields optimum annual net benefits. Conjunctive use of surface and ground water is not considered. Penalty function approach is used to convert constrained problem into an unconstrained problem. Simple crossover and mutation operators are employed. Results obtained by GA are compared with those of LP. It is concluded that GA is an effective optimization tool for irrigation planning and can be utilized for any similar irrigation system.

Genetic Algorithms, although not extensively applied to irrigation engineering applications have been applied to several optimization problems in water resources for water distribution and pipe network system by Reis *et al* (1997), Meier and Barkdoll (2000), Dandy and Engelhardt (2001), Samuel and Jha (2003), Cui and Kuczera (2003), Tolson *et al* (2004), Jakobus *et al* (2004) and ground water analysis by Gentry *et al* (2001), Yoon and Shoemaker (2001), Espinoza *et al* (2005), Hilton and Culver (2005) and Mahinthakumar and Sayeed (2005). It is observed from above studies that 1) application of GA for irrigation planning is limited, 2) conjunctive use of surface water and ground water is not considered, 3) Real-coded GA with simulated binary crossover operator and parameter based mutation operator has not been reported.

2.2.3 Differential Evolution

Differential Evolution (DE) is an evolutionary optimization technique, which is significantly faster, robust and has likely chances of finding true global optimum (Price and Storn, 1997). Price and Storn (2005) discussed the potential scientific applications of DE including that of researchers (Application No. 16, Homepage of Differential

Evolution, the URL of which is http://www.icsi.berkeley.edu/~storn/code.html). No other study has been reported on DE in irrigation planning.

2.2.4 Simulated Annealing

Simulated Annealing (SA) technique resembles the cooling process of molten metals through annealing. SA technique has the advantage of finding the global optimum with a high probability even for ill-conditioned functions with numerous local minima (Rao, 2003). Brief literature review of SA is as follows:

Ramesh and Simonovic (2002) applied SA to a case study of four-reservoir system previously solved using a linear programming formulation to maximize the benefits. SA is also applied to a system of four hydropower generating reservoirs in Manitoba, Canada, to derive optimal operating rules with an objective of minimizing the cost of power generation. Results obtained from these two applications suggest that SA can be used as an alternative approach for solving reservoir operation problems that are computationally intractable. Rao *et al* (2003) developed a management model within simulation (a sharp interface flow model) optimization (SA algorithm) framework to determine the optimal groundwater extraction in a hypothetical deltaic region with reference to Indian conditions. The objective is to determine optimal configuration of rates of pumpages and their location. They concluded that the model provided near-optimal solutions. Similar studies are reported by Cunha and Sousa (1999) and Rao *et al* (2004). Application of SA for the case study in irrigation planning context is limited except those reported by Kuo *et al* (2000).

2.2.5 Simulated Quenching

Simulated Quenching (SQ) is an efficient extension of SA. Simulated Quenching is significantly faster due to its annealing schedule. Simulated annealing slowly reduces the temperature of the system, thus gradually reducing the probability of accepting a move to a higher energy state whereas Simulated Quenching quickly reduces the temperature in the system and brings it to a minimum temperature (http://www.npac.syr.edu/users/paulc/

lectures/montecarlo/node148.html). No study of SQ is reported in irrigation planning context.

2.3 IRRIGATION SYSTEM PERFORMANCE

The sustainability of irrigation agriculture continues to be a priority issue in both developed and developing countries. Sustained development of irrigation agriculture is limited by shortages of suitable water supply and irrigable land. It is recognized that opportunities are available for substantial increase in agricultural output using existing water supply and project infrastructure through improvements in project management (including operations), modernization of project infrastructure, better maintenance and improved on-farm agriculture practices. Irrigation projects, once developed are expected to maintain agricultural productivity without significant subsidization over the long term. Also monitoring and evaluation of irrigation projects have received good attention in recent years. These evaluation processes provide valuable information for managers and decision makers regarding the long-term and short-term effectiveness of these projects (Karamouz *et al*, 2002). Related literature with reference to irrigation system performance is briefly reviewed below.

2.3.1 Performance Measures and Indicators

Biswas (1990) stressed the need for effective monitoring and evaluation of irrigation projects. He pointed out the primary requirements for effective monitoring as (1) timeliness (2) cost-effectiveness (3) maximum coverage (4) minimum measurement error (5) minimum sampling error (6) absence of bias (7) identification of users for information. Molden and Gates (1990) proposed performance measures such as adequacy, efficiency, dependability and equity of water delivery to provide a quantitative assessment of structural and management components of the system as well as the overall system performance. Spatial and temporal distributions of required, scheduled, deliverable and delivered water were estimated by field measurements and through simulation studies from which the above performance measures were calculated. They applied the methodology to a few typical systems of Sri Lanka and Egypt. Burt *et al* (1997) discussed the need to standardize the definitions and approaches to quantify various irrigation performance measures such as irrigation efficiency and uniformity. They proposed the techniques whereby the accuracy of numerical values of the performance indicators can be assessed. Thoreson *et al* (1997) described a framework for determining the effect of maintenance events on irrigation system flows. They suggested maintenance activities and decision criteria common to many irrigation systems. Bos (1997) described in detail the performance indicators, namely, water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio-economics and management. He recommended use of these indicators in irrigation and drainage performance assessment.

Dedrick *et al* (2000) tested three phased Management Improvement Program in the Maricopa-Stanfield Irrigation and Drainage District area in central Arizona, USA. The three-phased process consists of analysis of the current performance of the agricultural system, plans for improvement by the stakeholders and collaborative implementation of the plans. The developed methodology is found to be useful and satisfactory. Javan *et al* (2002) studied some of the water management problems of three different irrigation systems namely, Doroodzan project, Zayandeh Rud and Moghan project in Iran for both wet and dry seasons. Irrigation systems were evaluated on overall project water delivery efficiency and the monthly water requirement of crops. They concluded that the distribution and conveyance of water in the Doroodzan Irrigation Network was unreliable in both seasons. Water distribution equity along territories for other two projects was found to be poor.

Brito *et al* (2003) analyzed performance assessment of the Paracatu/Entre-Ribeiros irrigation project in Southeastern Brazil. Seven indicators, namely, delivery performance, overall consumptive ratio, sustainability of irrigated area, power and energy consumption, operation and maintenance fraction, unit gross economic return, and global revenue/cost ratio were used to assess the performance of the project from 1997 through 2000. They suggested the need for improvement of the current situation of the scheme. Brugere and Lingard (2003) studied the causes of irrigation deficits and farmer's vulnerability in Lower Bhavani Project in Tamil Nadu, India. They observed that lower returns from land due to insufficient water availability increased towards the tail end of the irrigation system. They concluded that irrigation deficit can be used as an indicator of farmer's vulnerability while assessing an irrigation system. Similar studies are reported by Hsu (1995) and Huppert *et al* (2003).

2.3.2 Response Survey Analysis

McCornick (1993) examined irrigation water management characteristics including on-farm scheduling practices of a lateral canal command in the Eastern Irrigation District, Alberta, Canada. Supply/demand ratios were used as the key indicators for the conceptual framework. A sample questionnaire was prepared to assess the water management characteristics in the command area. Walters *et al* (1999) conducted response survey in eight villages located in Bais Bay Basin, Negros Island, Philippines. It is concluded that characteristics like the degree of local knowledge, security of land tenure and community cohesion affected people's participation to a great extent.

2.3.3 Research and Methodological Needs

Grimble and Wellard (1997) stressed research and methodological needs such as acquiring empirical knowledge, understanding of the key stakeholders involved in the process, factors governing resource allocation procedures, frame work for analyzing situations, incorporating stakeholder and institutional concerns, developing knowledge of the opportunities and scope for action by policy-makers. The above features are discussed with reference to the case studies of the dipterocarp forest in north-east Thailand and the tropical forest of southern Cameroon. Burton *et al* (1999) stressed the need to improve the institutional, legal and social framework to facilitate change and the adoption of more water-use efficient technologies, practices and procedures. Stephens and Hess (1999) also suggested greater emphasis on more subjective and holistic approaches to define more clearly the researchable constraints in water management.

Pereira *et al* (2002) discussed the requirement of innovative and sustainable research and an appropriate transfer of technologies in water scarcity regions for agricultural production. They proposed concepts related to water scarcity, aridity, drought, desertification, water shortage and policies to cope with the water stressed regimes. They focused on demand management with aspects relating to the improvement of irrigation methods and their respective performances.

2.3.4 Application of MCDM Techniques in Performance Evaluation Studies

Multicriterion Decision Making techniques are found to be useful for ranking the available alternatives. Numerous MCDM techniques such as ELECTRE-3, PROMETHEE-2, Compromise Programming, Analytic Hierarchy Process, Multicriterion Q-Analysis, Multi Attribute Utility Theory, Co-operative game theory are employed for different case studies, namely, river basin planning (Gershon and Duckstein, 1983; Ko *et al*, 1994), hydropower operation (Duckstein *et al*, 1989), ground water planning (Duckstein *et al*, 1994), irrigation planning (Pillai and Raju, 1996; Raju and Nagesh Kumar, 1999), performance evaluation (Gates *et al* , 1991; Heyder *et al* ,1991; Raju and Pillai, 1999).

The important literature pertaining to MCDM techniques that are relevant to the present study are discussed briefly in the following sections and more details about MCDM techniques are available elsewhere (Pomerol and Romero, 2000).

2.3.4.1 Multicriterion Q-Analysis-2

Multicriterion Q-Analysis-2 approach is based on multidimensional graph theory (Johnson, 1981). It is a technique by which many alternatives can be compared simultaneously with respect to a set of criteria. The essence of MCQA-2 is to establish a preference matrix derived from payoff matrix.

Hiessl *et al* (1985) employed MCQA-2 to a case study involving control of waste water discharge into San Francisco Bay from the city of SanJose. Five criteria, recreational potential, NH_3-N concentration, land use, treatment cost and public acceptance were considered for five alternative policy scenarios. Payoff matrix was converted into preference matrix. Sensitivity analysis on slicing parameters indicated that optimum slicing parameters will be the values contained in the preference matrix. They concluded that MCQA-2 is quite robust to the change in weightages. Duckstein and Nobe (1997) studied MCQA-2 in detail and explained the methodology with numerous hypothetical examples. Raju and Nagesh Kumar (2001) applied MCQA-2 for ranking the alternative irrigation planning strategies for a case study of Sri Ram Sagar Project, Andhra Pradesh, India. They also used Compromise Programming for comparing the results of MCQA-2 and concluded that methodology can be applied for similar situations. Similar studies are reported by Pillai and Raju (1996).

2.3.4.2 Multi Attribute Utility Theory

Multi Attribute Utility Theory (MAUT) takes into consideration the decision maker's preferences in the form of utility functions which are defined over a set of attributes (Goicoechea *et al*, 1982).

Keeney and Wood (1977) employed MAUT to evaluate overall utility of five alternative water resources development plans for the Tisza river basin, Hungary. Twelve criteria, consisting seven of qualitative nature and five of quantitative nature, were used to evaluate the alternative plans. The utility function was of the multiplicative form. Ranking was based on the overall utility value of each alternative plan. Hayashi (1998) presented a methodology for aiding agricultural decisions using multi-attribute value models with interval numbers for a case study in Japan. He concluded that the proposed methodology provided a systematic framework for those farmers who are considering the introduction of new technologies. Raju and Pillai (1999) applied MAUT and stochastic extension of PROMETHEE to rank irrigation subsystems of Sri Ram Sagar Project, Andhra Pradesh, India and selected one subsystem as the best. They have done extensive sensitivity analysis and also discussed in depth about MAUT and its potentiality. Limon *et al* (2003) presented MAUT methodology for a case study located in Northern Spain, Los Canales del Bajo Carrion, in the county of Palencia. They estimated the risk aversion coefficients. It is concluded that farmers' showed decreasing absolute risk aversion. Similar studies are reported for locating and sizing desalination facilities by Mahmoud *et al* (2002).

2.3.4.3 Compromise Programming

Compromise Programming (CP) is a distance based MCDM technique to rank the alternatives (Zeleny, 1982). In this technique the solutions close to the ideal solution are identified by measure of L_p - metric distance.

Onta *et al* (1991) proposed a three step modeling approach for irrigation planning involving integrated use of surface and ground water resources for a case study of Bagmati river basin, Nepal. They employed CP to select the most satisfactory alternative plan and corresponding water allocation policy. Tiwari *et al* (1999) developed a framework for MCDM in the context of low land irrigated agriculture system for Phitsanulok irrigation project, Thailand. Environmental sustainability criteria such as land capability/suitability, energy input/output ratio, water demand and environmental costs are considered whereas economic sustainability is measured from farmers, governments and societal points of view in the forms of field surveys and discussions. It is concluded that MCDM techniques namely, Compromise Programming and Analytic Hierarchy Process provided useful guidance for selecting optimum cropping patterns.

2.4 CLASSIFICATION ASPECTS OF ARTIFICIAL NEURAL NETWORKS

An Artificial Neural Network (ANN) is a massively parallel distributed information processing system that has certain performance characteristics resembling biological neural networks of the human brain. ANN have been developed as a generalization of mathematical models of human cognition. On the other hand, clustering aspects of ANN are gaining importance as ANN is found to be suitable to reduce moderately large data sets to a manageable set.

Rao (2000a) investigated the role of ANN in hydrology. He described various aspects of ANN such as forecasting, classification, guidelines on their usage, strengths, limitations of ANN, merits and potential research avenues. He reviewed application of ANN for rainfall-runoff prediction, ground water management, water quality simulation and precipitation analysis etc., (Rao, 2000b). Thandaveswara and Sajikumar (2000) discussed the procedure for clustering of river basins based on hydro meteorological homogeneity for 55 basins in India. In the study, a combination of Adaptive Resonance Theory Type-II (ART-II) and back propagation network of ANN category is examined for clustering the basins on the basis of hydrological homogeneity. They compared the results with geographical classification and hierarchical clustering. The statistics indicated that ART-II clustering improved the performance of back propagation network prediction. They concluded that ART-II network could be used to identify the homogeneous groups and suggested that the data from more basins have to be employed to increase the reliability of the prediction of the runoff model. Similar studies are reported for classification of watersheds by Chiang *et al* (2002a, b). No study is explored using ANN in performance evaluation studies.

2.5 WEIGHTING OF CRITERIA

Analytic Hierarchy Process (AHP) is used to estimate weights of the criteria (Saaty and Gholamnezhad, 1982; Saaty, 1990). The technique deals with complex problems, which involve the consideration of multiple criteria simultaneously.

Palmer and Lund (1985) demonstrated AHP for the problem of network design for good aquatic monitoring. A two-level approach was considered with five activities and three sub-objectives. They also reviewed the theoretical aspects of the approach including measures of subjective inconsistency, the sensitivity of inconsistency to pairwise comparisons, subjective scaling factors, and sensitivity of weightages. Saaty (1990) also made an extensive review of AHP. Karamouz *et al* (2002) developed an algorithm to monitor and evaluate drip and pressure irrigation projects in Iran. Different indicators were identified and the framework of an integrated evaluation system was demonstrated using AHP. The results have shown the significant value of such systems in providing information and input for different decision making levels. Similarly, Raju and Pillai (1999), Raju and Duckstein (2002) used AHP for estimation of weights of performance criteria.

2.6 CORRELATION COEFFICIENT

Correlation Coefficient analysis is used by researchers to check the consistency between the ranks obtained by different scenarios or MCDM techniques. Hobbs (1984) discussed the necessity of rank correlation techniques to compute the correlation coefficient values among the ranks obtained by different MCDM techniques (Gibbons, 1971). He explained the applicability of Spearman Rank Correlation (SRC) technique for a river basin planning problem. Later Ko *et al* (1994), Pillai and Raju (1996), Raju and Nagesh Kumar (1999), Raju *et al* (2000), Hyde *et al* (2004) used SRC technique for various planning situations.

2.7 LIMITATION AND NEED FOR FURTHER INVESTIGATIONS

(i) Very few or no studies are reported in the optimal reservoir operation for irrigation planning using non-traditional optimization techniques, such as Real-coded Genetic Algorithms, Differential Evolution, Simulated Annealing and Simulated Quenching.

(ii) Very few real world applications of MCDM methodologies for performance evaluation are reported. MCDM techniques such as Compromise Programming and Multicriterion Q-Analysis-2 (in addition to MAUT) need to be explored to rank the irrigation subsystems.

(iii) Non-traditional techniques such as Genetic Algorithms, Differential Evolution, Simulated Annealing and Simulated Quenching requires further investigations for solving high dimensional problems (more constraints and variables) and their applicability in irrigation planning.

(iv) Systematic and effective methodology is required to group the irrigation subsystems.

(v) Intensive studies are necessary to know the irrigation system characteristics, farmers' views and opinion of officials while evaluating the system performance which may be the basis for further improvement.

(vi) Alternative methodologies are needed to solve a similar problem for comparative purposes as more than one methodology always enhances the decision making capabilities effectively.

The present study pursues all these investigations and the results are applied to Mahi Bajaj Sagar Project in Rajasthan, India, the details of which are described in the next chapter.

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CHAPTER

3

DESCRIPTION OF THE SYSTEM AND THE FORMULATION OF OBJECTIVES BASED ON RESPONSE SURVEY ANALYSIS

3.1 GENERAL

This chapter presents an overview of the planning environment relevant to the command area under consideration. Specifically it considers the salient features of the irrigation project along with its physical setting, cropping pattern, geology, climate, ground water status and socio-economic aspects. The constraints in utilizing the resources in the command area are assessed through discussions with project officials at various levels, interactions with farmers' in the form of interviews using a structured questionnaire and available project reports. This helped to understand the existing water management practices better and developed the basis for systematic approach for the improvements of the system.

3.2 PHYSICAL SETTING

3.2.1 Location

Mahi Bajaj Sagar Project (MBSP) is located in Banswara district in southern part of Rajasthan state bordering the states of Madhya Pradesh and Gujarat. The project is situated near a village Borkhera about 16 Km northeast of Banswara town. Global co-ordinates of the site are $24^{\circ}22'$ N Latitude and $73^{\circ}19'$ E Longitude (Water Resources Planning for Mahi River Basin, 2001). The project includes a dam, a system of canals and two hydroelectric power houses *PH 1* located near Banswara with installed capacity of 2x25 MW and *PH 2* near Lilvani village with installed capacity of 2x45 MW.

The MBSP has three main canal systems namely, Left Main Canal (LMC), Right Main Canal (RMC) and Bhungra Canal (BC). Four other canals, namely, Anandpuri canal comes under LMC and Narwali canal, Jagpura canal and Bhikha Bhai Sagwara canal come under RMC (MBSP Report on Status June 2002 at a Glance, 2002).

The two canals LMC and RMC takes off from balancing reservoir i.e., Kagdi Pick Up Weir. The RMC is an irrigation canal while, LMC is an irrigation cum hydel canal as it transmits the share of water of Gujarat state upto *PH 2*. Bhungra canal takes off from main dam and Anandpuri canal takes off from the tail of the hydel canal (LMC). Similarly Narwali canal takes off from RMC at 29.34 Km and Jagpura canal takes off from Narwali canal at 19.43 Km. Bhikha Bhai Sagwara canal starts from the tail of RMC. Location map of MBSP is shown in Fig. 3.1. Index map of MBSP giving the details of canals is presented in Fig. 3.2. Salient features of MBSP and details of the canal distribution systems and corresponding Culturable Command Areas (CCA) are presented in Tables 3.1 and 3.2 (MBSP Report on Status June 2002 at a Glance, 2002).

The releases from the reservoir are made through the saddle dams (because of natural depression) constructed at the bank of the reservoir. From the saddle dam, the water goes to *PH 1* and then to the Kagdi Pick up Weir from which water is released into LMC and RMC (Nagesh Kumar, 2004).

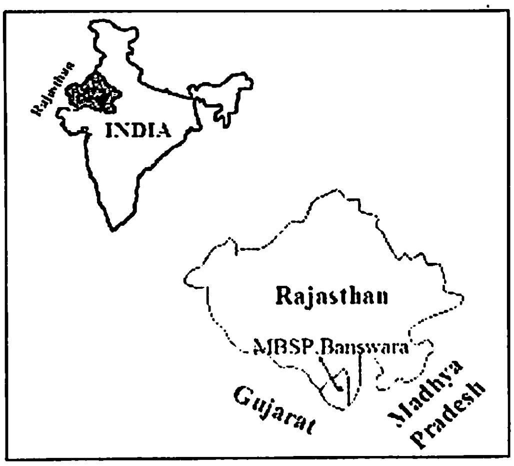

Fig. 3.1 Location map of Mahi Bajaj Sagar Project (MBSP)
(Source: MBSP Report on Status June 2002 at a Glance, 2002)

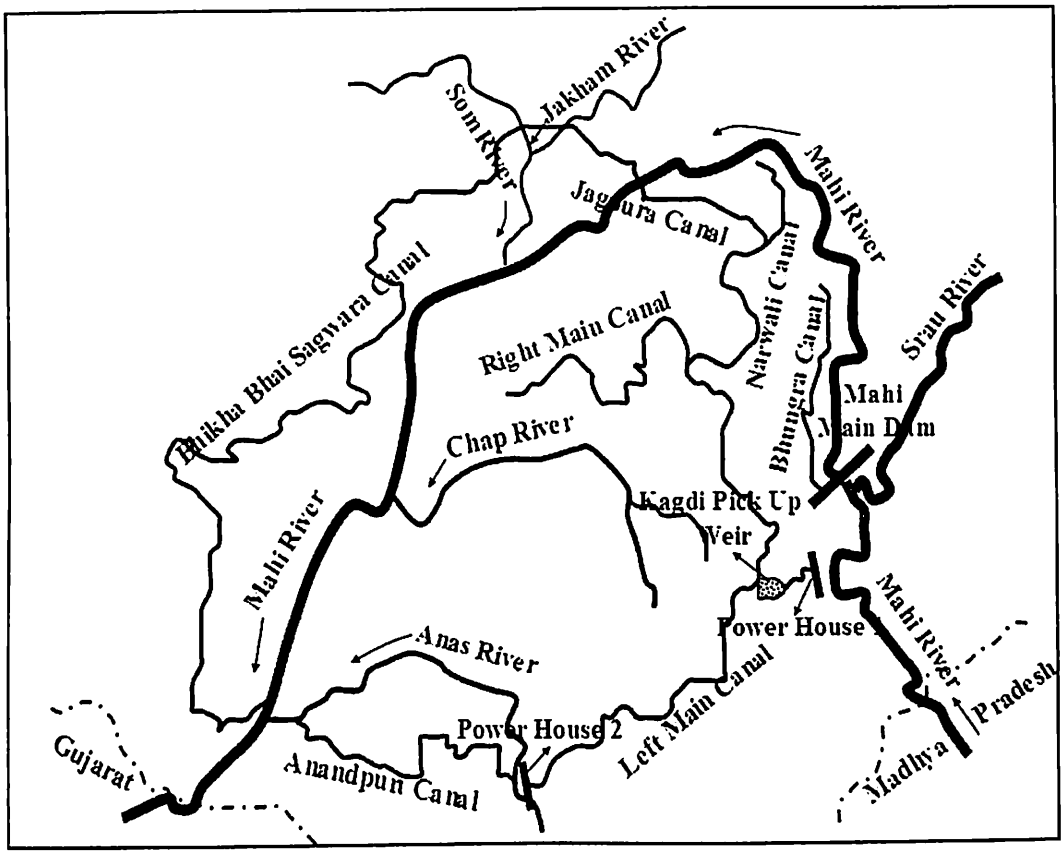

Fig. 3.2 Index map of Mahi Bajaj Sagar Project (MBSP)
(Source: MBSP Report on Status June 2002 at a Glance, 2002)

Table 3.1 Salient features of Mahi Bajaj Sagar Project (MBSP)
(Source: MBSP Report on Status June 2002 at a Glance, 2002)

Full Reservoir Level	EL 281.50 m
Water Spread Area	142.90 Km^2
Gross Storage (Live + Dead) Capacity	2180.39 Mm^3
Live Storage Capacity	1829.27 Mm^3
Dead Storage Capacity	351.13 Mm^3
Sharing of Water	Gujarat State 1132.67 Mm^3
	Madhya Pradesh 368.11 Mm^3
Culturable Command Area (CCA)	80,000 ha (Phase 1)
	1,23,500 ha (Phase 2)
Power House 1 (*PH 1*) Installed Capacity	2x25 MW
Power House 2 (*PH 2*) Installed Capacity	2x45 MW

Table 3.2 Details of canal systems

(Source: MBSP Report on Status June 2002 at a Glance, 2002)

Name of the Canal	Discharge at head (cumecs)	Length (km)	Culturable Command Area (ha)
Left Main Canal	62.53	36.12	40570
Right Main Canal	30.00	71.72	35940
Bhungra Canal	3.19	39.80	3490
Anandpuri Canal	4.40	39.93	9000
Narwali Canal	17.22	33.09	2055
Jagpura Canal	12.32	12.50	2570
Bhikha Bhai Sagwara Canal	2.06	21.46	4956

3.2.2 Inter-state Agreement

An inter-state bilateral agreement regarding sharing of Mahi water between Rajasthan and Madhya Pradesh was made in 1961 to utilize the Mahi river water potential for development of most backward tribal region of both states. Similar understanding was also made between the states of Gujarat and Rajasthan in the year 1966. Accordingly it was agreed to reserve 368.11 Mm^3 of Mahi water for upstream utilization in Madhya Pradesh and 1132.67 Mm^3 for downstream utilization in Gujarat (Mahi Bajaj Sagar Project Report, 1978).

3.2.3 Characteristics of the Soils and Geology of the area

The soils of the area are categorized under black, red, brown and mixed soils (Mahi Bajaj Sagar Project Report, 1978). The black soils exist along LMC, head reaches of taking off irrigation subsystems and the patches along RMC. Red soils and brown soils are found both in LMC and RMC command. The command area is covered mainly by rocks belonging to the Archaean metamorphic complex and the Aravali super-group of rocks. Alluvium presence is insignificant.

3.2.4 Climate

The area is classified as semi-arid. May is the hottest month of the year, with a mean daily maximum and minimum temperature of 40.5 °C and 27.5 °C respectively. The annual range in temperature, i.e., the difference between the extreme maximum and minimum temperatures reaches about 42 °C. The mean monthly maximum and minimum temperatures, humidity, wind speed, daily sunshine and solar radiation for Banswara station (representing MBSP) are shown in Table 3.3 (Water Resources Planning for Mahi River Basin, 2001) which is the basis for computation of reference evapotranspiration (ET_o), thereby crop water requirements and crop diversion requirements.

Table 3.3 Meteorological data of Banswara station (representing MBSP)
(Source: Water Resources Planning for Mahi River Basin, 2001)

Month	Max. Temp (°C)	Min. Temp (°C)	Humid-ity (%)	Wind Speed (Km/day)	Daily Sun-shine (hrs)	Solar Radiation (MJ/m^2/d)
January	27.5	12.1	46.6	120.0	7.6	14.8
February	30.2	14.6	41.7	134.4	7.2	16.3
March	34.9	19.3	37.3	146.4	8.4	20.2
April	39.4	24.1	35.2	146.4	8.6	22.2
May	40.5	26.4	52.7	218.4	9.3	24.0
June	37.2	25.8	67.8	235.2	9.2	23.8
July	31.8	24.2	74.4	182.4	9.4	24.0
August	29.9	23.4	81.2	158.4	9.1	23.1
September	32.6	22.8	75.1	105.6	8.3	20.6
October	34.8	20.3	54.6	108.0	8.1	18.1
November	32.4	16.9	47.5	115.2	7.4	15.0
December	28.7	13.3	53.5	117.6	7.4	13.9
Average	33.3	20.3	55.6	149.0	8.3	19.7
Minimum	27.5	12.1	35.2	105.6	7.2	13.9
Maximum	40.5	26.4	81.2	235.2	9.4	24.0

It is observed from Table 3.3 that relative humidity during the southwest monsoon season is about 80%. During the rest of the year, the air is normally dry. Winds are generally light in the post-monsoon and winter months. Mean wind speed is highest in June (235.2 Km/day) and lowest in September (105.6 Km/day). On an average there are 53 rainy days (i.e., days with rainfall of 2.5 mm or more) in a year. It is observed that the mean annual rainfall is 700 mm, of which about 94% falls during the four monsoon months (June-September), with July and August accounting for 32% and 36% of the annual rainfall (Water Resources Planning for Mahi River Basin, 2001).

3.2.5 Ground Water Status

Ground water in the project is of high quality and is suitable for all purposes. Hydraulic gradients are rather steep and salt accumulation is prevented by the continuous flow of fresh water. The annual ground water potential is 124.27 Mm^3/yr as per statistics available in 1978. For the present study, it is taken as 25% of the estimated potential i.e., 31.07 Mm^3/yr as per discussion with officials of the project (Mahi Bajaj Sagar Project Report, 1978).

3.3 CROPPING PATTERN AND INTENSITY OF IRRIGATION

The principal crops grown in the command area in Kharif and Rabi seasons are Paddy, Cotton, Wheat, Gram, Pulses, etc. The intensity of irrigation in the pre-project era was proposed as 80 % (64 % Rabi and 16 % Kharif). This has been increased to 89 % (64 % Rabi and 25 % Kharif) in the post project era. The existing cropping pattern is shown in Table 3.4 (MBSP Report on Project Estimate of Unit-II, 2001).

3.4 FARMING COMMUNITY

It is observed that the population is mostly economically backward (Mahi Bajaj Sagar Project Report, 1978). The farmers' include both the landless agricultural labourers and the land owning farmers' in the command area. While the land owning farmers' work mostly on their farms, the landless agricultural labourers are employed for peak agricultural operations like sowing and harvesting. The economic condition of these landless labourers is very poor. Various training programs are being organized by the government in sustainable irrigation planning and management, modern farm practices, thus improving their job performance and consequently wages. Training programs are also found to be useful in increasing agriculture production in the irrigated areas, implementing participatory irrigation management practices and transferring the recent advances in technology to the farmers' and officials in the command area.

Table 3.4 Existing cropping pattern in the command area
(Source: MBSP Report on Project Estimate of Unit-II, 2001)

Season	Crops		LMC (40570 ha)	RMC (35940 ha)	BC (3490 ha)
	Name	%			
Rabi (64%)	Wheat	30.0	12171.00	10782.00	1047.00
	Barley	4.2	1703.94	1509.48	146.58
	Gram	25.2	10223.64	9056.88	879.48
	Barseen	1.9	770.83	682.86	66.31
	Mustard	2.2	892.54	790.68	76.78
	Fruits & Veg.	0.5	202.85	179.70	17.45
	SUBTOTAL	64.0	25964.80	23001.60	2233.60
Kharif (25%)	Maize	3.0	1217.10	1078.20	104.70
	Paddy	4.0	1622.80	1437.60	139.60
	Cotton	9.0	3651.30	3234.60	314.10
	Pulses	5.0	2028.50	1797.00	174.50
	Sugarcane	2.0	811.40	718.80	69.80
	Zaid Crop	2.0	811.40	718.80	69.80
	SUBTOTAL	25.0	10142.50	8985.00	872.50
	TOTAL	89.0	36107.30	31986.60	3106.10

3.5 RESPONSE SURVEY AND ITS ANALYSIS

Farmers' response survey is carried out in sixteen irrigation subsystems of MBSP by designing a structured questionnaire. The objective of the survey is to assess their reaction to irrigation schedules and deliveries, their socio-economic status and constraints faced in the optimum utilization of resources. This also helped in comparing the performances in different reaches of irrigation system based on different criteria. Index map of sixteen irrigation subsystems of MBSP are presented in Fig. 3.3. The hydraulic details, culturable command areas, number of farmers' surveyed and the villages benefited by each irrigation subsystem are shown in Table 3.5.

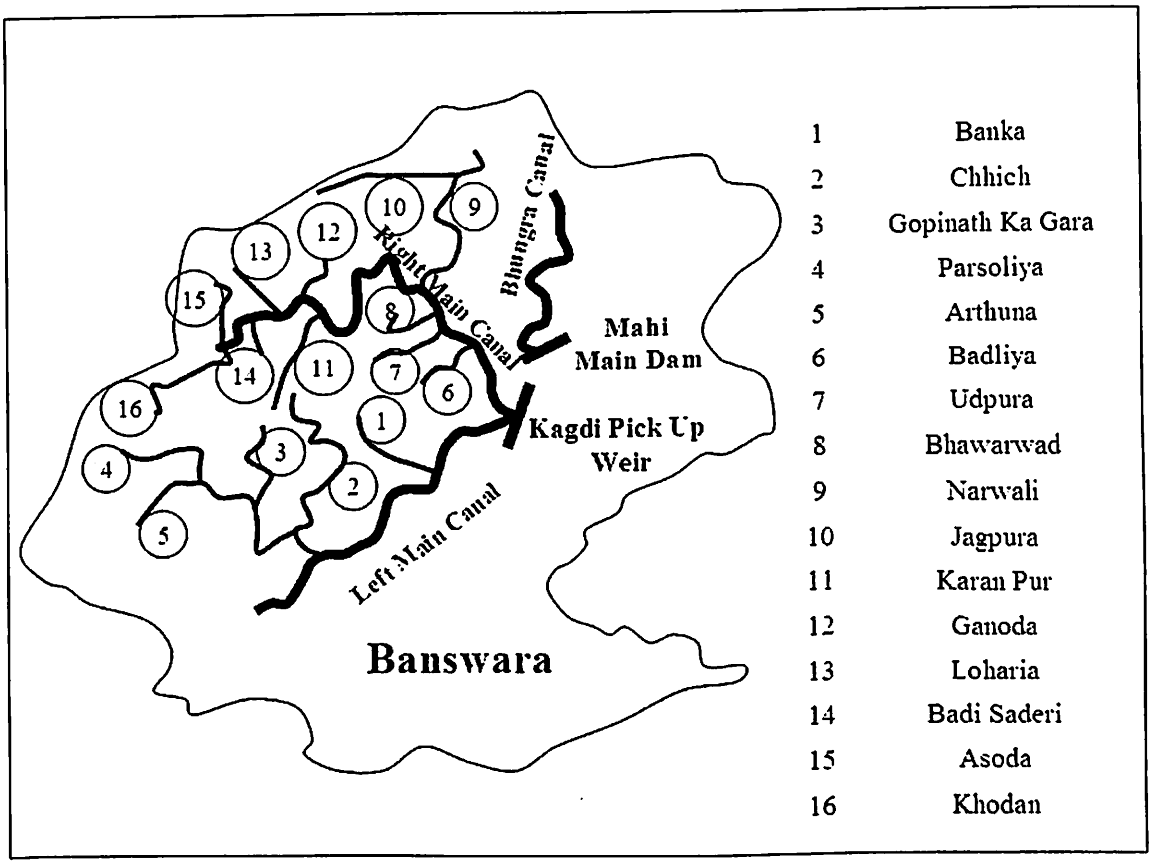

Fig. 3.3 Index map of sixteen irrigation subsystems of Mahi Bajaj Sagar Project (Source: MBSP Report on Status June 2002 at a Glance, 2002)

Table 3.5 Details of irrigation subsystems of Mahi Bajaj Sagar Project (Source: MBSP Report on Status June 2002 at a Glance, 2002)

IS. No.	Irrigation Subsystem	Discharge (Cumecs)	Length (Km)	CCA (ha)	Total No. of Farmers' Interviewed	No. of Farmers' after screening	Villages covered by the irrigation subsystem
IS1	Banka	2.14	13.70	952.00	16	15	Khupda, Ganpatpura, Somaliya, Badghanv, Purthiya
IS2	Chhich	9.76	44.22	9130.00	21	14	Bansla, Chackla, Shambupura, Talwada, Masotia
IS3	Gopinath Ka Gara	1.85	24.00	3150.00	16	11	Jholna, Malwa, Khuwadiya, Parahera, Gopinath ka gara
IS4	Parsoliya	2.49	21.72	7855.00	19	14	Chittori, Raiyana, Ratanpura, Jhadasi, Parsoliya
IS5	Arthuna	7.98	40.80	5881.00	19	14	Bodigama, Bathaar, Nahli, Khadwal, Govindpur
IS6	Badliya	0.58	9.75	1619.00	15	12	Tejpur, Chidiyawas
IS7	Udpura	0.82	6.12	2327.00	17	12	Udpura, Kuwania
IS8	Bhawarwad	0.68	4.23	2139.00	16	12	Amarvor, Charla, Nawai
IS9	Narwali	16.98	33.09	10722.00	24	16	Ghatol, Vadanpura Hawani, Bhemroll, Rayali, Sarodiya,
IS10	Jagpura	0.88	8.30	1312.00	14	12	Surpur, Makanpura, Amarjala, Jagpura
IS11	Karan Pur	0.76	7.05	2095.00	17	14	Sundhani, Nilariya, Moyawavsa
IS12	Ganoda	0.99	6.47	1977.00	16	15	Chirol, Ganoda, Siltiya, Kakarji Ka Para, Khudara
IS13	Loharia	0.46	12.43	1562.00	14	11	Bhuwasa, Loharia, Barsi
IS14	Badi Saderi	0.84	10.50	2302.31	18	11	Parkhelia, Baltika, Khagariya Ka Gara
IS15	Asoda	1.09	12.69	3328.00	18	11	Samagara, Paloda, Thikariya
IS16	Khodan	1.22	26.07	3944.41	20	14	Metwala, Pickora, Rohania, Agarpura, Bhankawara, Lohania
			Total	60295.72	280	208	

The questionnaire is designed in such a way that all the questions were simple, direct and unambiguous. The questionnaire was prepared in Hindi for meaningful interaction with the farmers'. A large number of farmers' were requested to participate in the response survey. The response from the farmers' was very encouraging. Efforts were made to select the farmers' who had minimum educational qualifications and those who had enough knowledge of their respective irrigation subsystems. Care had been taken to choose farmers' from head, middle and tail reaches of each irrigation subsystem. Hypothetical examples regarding answering the questions were orally demonstrated to them. Farmers' response survey questionnaire was distributed to the farmers' of sixteen irrigation subsystems of MBSP. Opinions of 208 farmers' out of 280 interviewed were considered after screening their responses. Farmers' response survey questionnaire is translated from Hindi into English and presented in Appendix A.

The response survey questionnaire consists of five sections.

Section 1 – General Details, Location and Water Source: Details such as farmer's name, name of the village in which the irrigation subsystem is located, area and location of the field i.e., head, middle or tail end are required to be provided in this section. Information such as source of water namely, authorized off take, reuse of drains, wells or other sources if any are also to be provided.

Section 2 - Cropping Intensity and Yields: Crop(s) that are grown in Kharif, Rabi and others in irrigation subsystem are to be provided. Similarly, the yield status of each crop is also to be given. In the response survey questionnaire, this information can be given in the form of qualitative characteristics such as very good, good, average, satisfactory and unsatisfactory due to non-availability of precise numerical values.

Section 3 - Water Supply: Information related to water supply is to be provided. Questions such as whether the amount of rainfall in the irrigation subsystem is more than average, average or less than average are posed to the farmers'. Similar questions on canal water cost are also posed. This is essential to assess distribution pattern of water with economic considerations.

Section 4 – Miscellaneous: The posed questions are related to operation and maintenance work, formation of farmers' group at pipe/distributory level, critical periods of crops, awareness of policies of the government and quality of water supplied. Similarly, farmers' were also asked whether post project era has helped them in terms of increasing agricultural production, income or more employment.

Section 5 – Assessment of Performance Criteria: Queries relevant to performance criteria that are important for the formulation of the payoff matrix are posed. These are regarding change in irrigated area (as compared to pre-project era), change in wages of agricultural labourers (as compared to pre-project era), crop productivity per unit of water, crop diversification, status of land leveling and development work, supply of other inputs, status of conjunctive use of water resources, farmers' participation, economic impact of irrigated agriculture, crop productivity and environmental conservation. The summary of the response survey questionnaire helped in understanding the various characteristics of the irrigation subsystems more effectively.

Appendix B presents irrigation subsystem-wise responses of farmers' which is self-explanatory. Table 3.6 presents the summarized report of farmers' response survey. It includes 208 farmers' opinions (head, middle, tail-wise) of the sixteen irrigation subsystems of the Mahi Bajaj Sagar Project with reference to Appendix B. Table 3.7 presents summarized report of farmers' response survey (percentage-wise).

It is observed that 46 % of the farmers' use water for irrigation from wells during peak season. It is felt that the canal water cost is reasonable and the quality of water supplied is satisfactory. Farmers' are aware of the critical periods of the crops grown in the command area and are interested in participating in the operation and maintenance of the canals.

Table 3.6 Summarized report of farmers' response survey (Head, Middle, Tail-wise)

		Head		Middle		Tail	
Number of Farmers'	Total: 208	82		49		77	
S.No.	Questions						
1.	Most of the Irrigation is taken from						
	• Authorized Off take	82		49		77	
	• Reuse of Drains	0		1		1	
	• Wells	41		17		38	
	• Others	0		1		0	
2.	Is the rainfall amount						
	• More than Average	0		0		1	
	• Average	80		44		75	
	• Less than Average	2		5		1	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	82	0	48	1	76	1
4.	Are you interested to participate in O & M works?	82	0	49	0	77	0
5.	Have farmers' group been formed at the pipe/distributory level?	0	82	0	49	0	77
6.	Are you aware of the critical periods of the crops grown by you?	80	2	48	1	76	1
7.	Are you aware of the crop and input price policies of the Government?	79	3	45	4	75	2
8.	Are you satisfied with the quality of water being supplied to you?	81	1	49	0	77	0
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	70	12	41	8	63	14
	• By way of increasing income	80	2	42	7	72	5
	• By way of getting employment	82	0	48	1	75	2

Table 3.7 Summarized report of farmers' response survey (Percentage-wise)

		Total	
Number of Farmers'		208	
S.No.	Questions		
1.	Most of the Irrigation water is taken from		
	• Authorized Off take	100	
	• Reuse of Drains	0.96	
	• Wells	46.15	
	• Others	0.48	
2.	Is the rainfall amount		
	• More than Average	0.48	
	• Average	95.67	
	• Less than Average	3.85	
		Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	99.04	0.96
4.	Are you interested to participate in O & M works?	100	0
5.	Have farmers' group been formed at the pipe/distributory level?	0	100
6.	Are you aware of the critical periods of the crops grown by you?	98.08	1.92
7.	Are you aware of the crop and input price policies of the Government?	95.67	4.33
8.	Are you satisfied with the quality of water being supplied to you?	99.52	0.48
9.	Would you say that this irrigation project has benefited the farmers' in the project area		
	• By way of increasing agricultural production	83.65	16.35
	• By way of increasing income	93.27	6.73
	• By way of getting employment	98.56	1.44

While approximately 84 % of farmers' agree that the irrigation project has benefited them in the post-project era by way of increasing agricultural production, 93 % of them of increasing income and 99 % of farmers' getting employment. During interactions, number of officials of the project also gave their overall opinion and information about the irrigation subsystems they were acquainted with. This also helped the researcher to analyze the system better.

Some of the responses which emanated from the formal and informal discussions with the farmers' and officials of Mahi Bajaj Sagar Project are:

- Farmers' felt that double cropping is essential to satisfy the increasing food demands of the region.
- Farmers' opined that whenever there are releases from the reservoir, the farmers' in head have sufficient water whereas those in tail end suffer due to lack of water.
- Farmers' at tail end felt that water remains as the main constraint but not the land. Lack of reliable water supply prevents them from planning their crops in advance with more reliability.
- Farmers' are interested in effective water user's association.
- Farmers' face minor difficulties in land development works in certain parts of command area.
- It is felt by the officials that the cropping pattern should be based on available water resources and food requirements.
- It is felt by the officials that interacting with group of farmers' is always proved to be beneficial instead of interacting with farmer's individually.
- Officials opined that price of water should not depend on the crop grown per hectare (existing practice) but to be based on the quantity of water used. They also felt that the water rates are to be revised significantly to avoid the wastage of water.
- Both farmers' and officials felt that incentives are to be given to the farmer(s) who saves considerable amount of water.

- Both farmers' and officials felt that training to farmers' and officials regarding improved knowledge of irrigation system, inter-disciplinary approach to operation and management is essential for sustainable irrigation planning.

3.6 OBJECTIVES OF THE STUDY

In the light of the outcome from response surveys, interviews, discussions, social and economic conditions of the farmers' and possible improvements as discussed in Chapter 1, the following objectives are formulated in two parts for modeling and planning of the MBSP command area:

PART 1: OPTIMAL RESERVOIR OPERATION FOR IRRIGATION PLANNING

1. Formulation of irrigation planning model considering conjunctive use of surface and ground water resources with the objective of achieving maximum annual net benefits.
2. Study the applicability of four non-traditional optimization techniques, namely, Real-coded Genetic Algorithm (RGA), Differential Evolution (DE), Simulated Annealing (SA) and Simulated Quenching (SQ) for the irrigation planning model and assessing their potentiality in solving high dimensional problems.
3. Comparative assessment of annual net benefits, cropping pattern, release, storage and ground water pumping policies for the above four methodologies with that of Linear Programming (LP).
4. Extensive sensitivity analysis of various parameters employed in four non-traditional optimization techniques to assess their effect on annual net benefits.

PART 2: PERFORMANCE EVALUATION STUDIES FOR IRRIGATION SUBSYSTEMS

5. Formulation of payoff matrix (irrigation subsystems versus performance criteria) based on farmers' responses and analyst's perception.
6. Weightage estimation of the various performance criteria by Analytic Hierarchy Process (AHP).

7. Grouping of the irrigation subsystems based on the Kohonen Artificial Neural Networks (KANN) methodology.
8. Ranking of the irrigation subsystems by different Multicriterion Decision Making (MCDM) techniques, namely,
    1. Multicriterion Q-Analysis 2 (MCQA-2)
    2. Multi Attribute Utility Theory (MAUT)
    3. Compromise Programming (CP)
9. Assessing the correlation between different MCDM techniques using Spearman Rank Correlation (SRC) technique.

The above two methodologies (Part 1, 2) are validated through case study of Mahi Bajaj Sagar Project, Rajasthan, India and presented in Figs. 3.4 and 3.5.

- Both farmers' and officials felt that training to farmers' and officials regarding improved knowledge of irrigation system, inter-disciplinary approach to operation and management is essential for sustainable irrigation planning.

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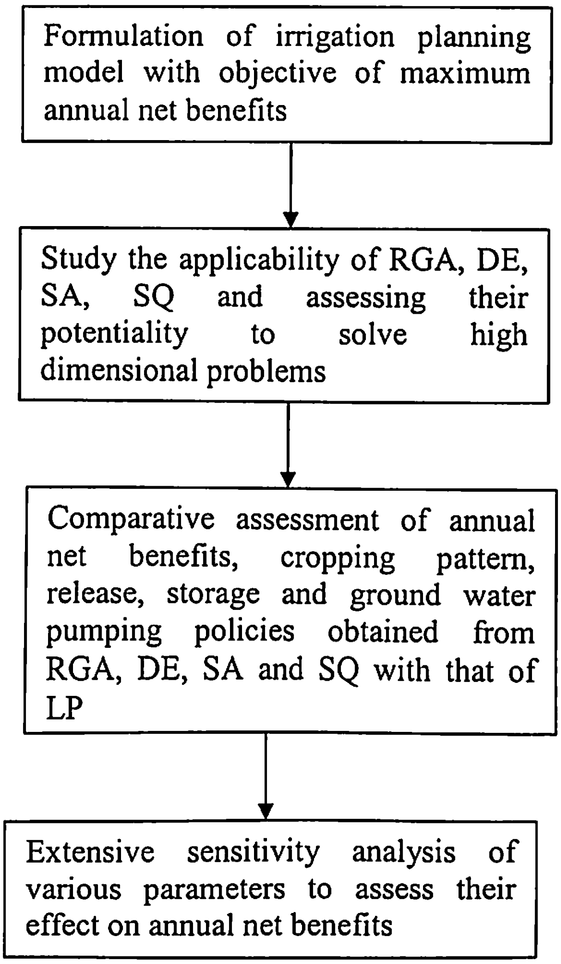

Fig. 3.4 Methodology of the proposed work (Part 1)

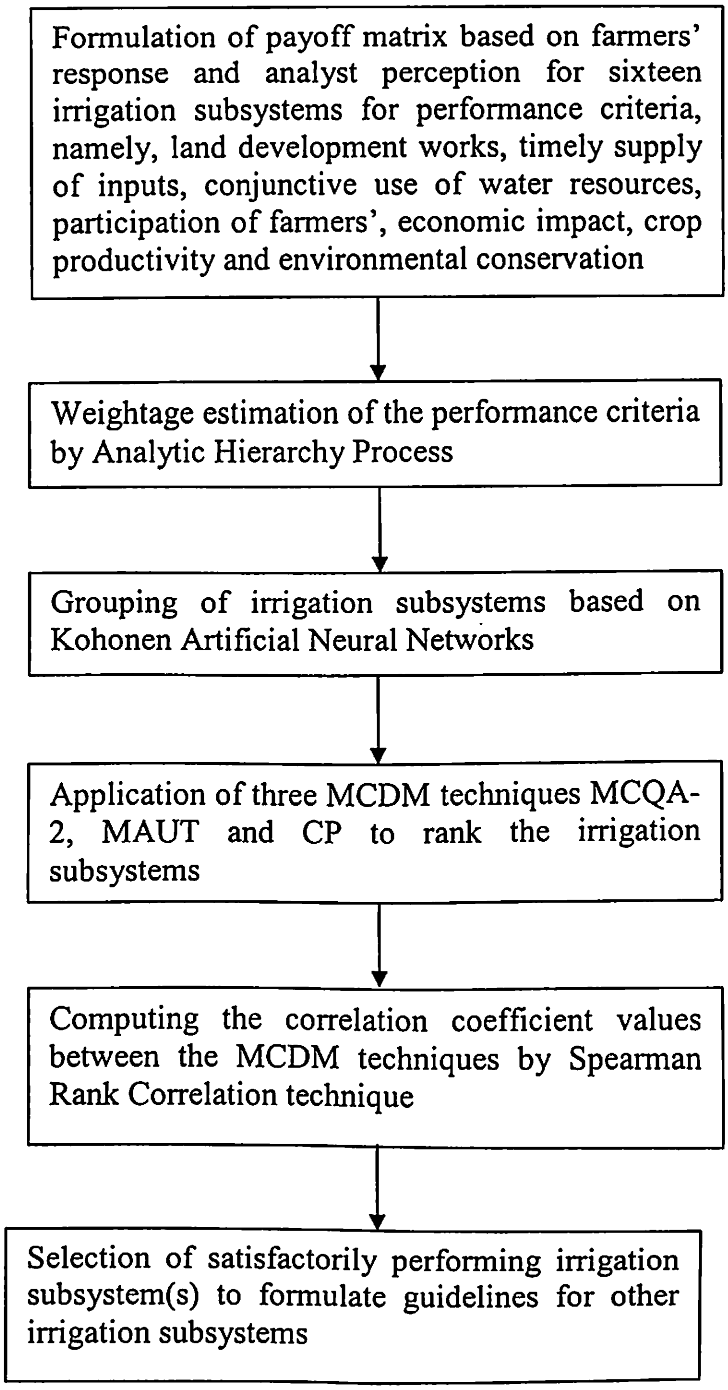

Fig. 3.5 Methodology of the proposed work (Part 2)

Next chapter describes the mathematical modeling of the case study of irrigation planning of MBSP, description of solution methodologies and comparative assessment of the same. It also discusses the necessity of performance evaluation studies and the relevant techniques that are used in this regard.

CHAPTER 4

MATHEMATICAL MODELING AND SOLUTION TECHNIQUES

4.1 GENERAL

The operation and management of irrigation systems are of growing concern worldwide. This is especially true for developing countries where the need to enhance the agricultural productivity is coupled with optimum utilization of available water resources not only for irrigation but also for other competing sectors (Lenton 1994; Wichelns, 2004). To overcome this problem, it is necessary either to bring more area under cultivation or to increase the productivity with the available resources or both. Bringing additional area under irrigation may be difficult due to rapid urbanization and other infrastructural requirements. Also, the allocation of water for irrigation may decrease from the present level of 90 % to 75-80 % over the next 10-15 years due to urbanization (Sivanappan, 1995). Due to the dwindling supply of water, the profit-conscious irrigators like to optimally allocate the available water and other resources for irrigation to maximize the annual net benefits. The allocation of water is required to be optimized over time, among the crops. In this regard, relevant solution methodologies are required for efficient irrigation planning that help to provide optimum allocation of resources. The present study is divided into two parts as mentioned in Chapter 3.

In **Part 1** of the study, four non-traditional optimization techniques, namely, Real-coded Genetic Algorithm (RGA), Differential Evolution (DE), Simulated Annealing (SA) and Simulated Quenching (SQ) are employed (1) to study their applicability in irrigation planning, (2) to assess their capability in solving high dimensional problems (more variables and constraints) irrespective of whether the model is linear or nonlinear and (3) to explore as alternative methodologies which will enhance the decision making capabilities (Raju and Nagesh Kumar, 2004). The results obtained from the non-traditional techniques are compared with Linear Programming (LP). In the present study, above mentioned optimization techniques are used to demonstrate their potentiality for real world irrigation planning problem of Mahi Bajaj Sagar Project (MBSP) that consists of numerous constraints and variables. Extensive sensitivity analysis is also made.

In **Part 2** of the study, evaluation of sixteen irrigation subsystems of MBSP is made to select the satisfactorily performing irrigation subsystem. Decision making techniques that are used in this endeavour are Kohonen Artificial Neural Networks (KANN), Multicriterion Q-Analysis-2 (MCQA-2), Multi Attribute Utility Theory (MAUT), Compromise Programming (CP), Analytic Hierarchy Process (AHP) and Spearman Rank Correlation (SRC). The present chapter describes the mathematical modeling of irrigation planning for the case study of MBSP, solution techniques that are employed in Part 1 and Part 2 of the studies in detail.

4.2 MATHEMATICAL MODELING OF IRRIGATION PLANNING (PART 1)

The present study is aimed to find the optimal cropping pattern, storage, release and ground water pumping policies that achieves optimum annual net benefits with the constraints such as land availability, water resources, storage and canal capacity, crop diversification considerations, etc. Various assumptions such as (1) all the relationships within the model are linear, (2) each unit of land under consideration for a particular activity is homogeneous and under the same type of management practices and (3) timing and period of cropping are constant and do not vary over years are made after discussions with project officials and experts while formulating the mathematical model.

Mathematical modeling of the irrigation planning problem of MBSP command area is explained below.

4.2.1 Objective Function: Maximization of Annual Net Benefits

The annual net benefits (*BEN*) from planning region under different crops after meeting where S_{t+1} =Reservoir storage volume at the end of month t or at the beginning of month $(t+1)$ (Mm^3); I_t =Monthly inflows into the reservoir (Mm^3); IDB_t =Irrigation demand for Bhungra canal for the month t (Mm^3); $PH1_t$ =Water requirement for Power House 1 for the month t (Mm^3); EV_t =Monthly evaporation loss (Mm^3); $USMP_t$ =Upstream requirement of water to Madhya Pradesh for the month t (Mm^3).

The above constraint assumes that the monthly inflows into the reservoir are known with certainty. When uncertainity is incorporated in the inflow terms, the above equation changes to

$$S_{t+1} - S_t + IDB_t + PH1_t + EV_t + USMP_t = I_t^{\alpha'}; \quad t = 1, \ldots 12 \qquad (4.3)$$

where $I_t^{\alpha'}$ is dependable inflow value at level α'. Details are presented in Section 5.3.

4.2.3 Continuity Equation at Kagdi Pick Up Weir

The Kagdi pick up weir acts as a balancing reservoir and water released from Power House 1 and the available ground water potential should satisfy the demands of Left Main canal, Right Main canal, Power House 2 for each month t. Conjunctive use of ground water with surface water is also considered in Eq. 4.4.

$$PH1_t + GW_t \geq IDL_t + IDR_t + PH2_t; \quad t = 1, \ldots 12 \qquad (4.4)$$

where IDL_t =Irrigation demand for Left Main canal for the month t (Mm^3); IDR_t =Irrigation demand for Right Main canal for the month t (Mm^3); $PH2_t$ =Water requirement for Power House 2 for the month t (Mm^3).

4.2.4 Command Area Limitations

The total area allocated for different crops in a particular season should be less than or equal to the Culturalable Command Area (CCA).

$$\sum_i A_i \le p_{ki}.CCA_L; \quad i = 1,...6 \qquad \text{Kharif Season} \qquad (4.5)$$

$$\sum_i A_i \le p_{ri}.CCA_L; \quad i = 7,...12 \qquad \text{Rabi Season} \qquad (4.6)$$

$$\sum_i A_i \le p_{ki}.CCA_R; \quad i = 13,...18 \qquad \text{Kharif Season} \qquad (4.7)$$

$$\sum_i A_i \le p_{ri}.CCA_R; \quad i = 19,...24 \qquad \text{Rabi Season} \qquad (4.8)$$

$$\sum_i A_i \le p_{ki}.CCA_B; \quad i = 25,...30 \qquad \text{Kharif Season} \qquad (4.9)$$

$$\sum_i A_i \le p_{ri}.CCA_B; \quad i = 31,...36 \qquad \text{Rabi Season} \qquad (4.10)$$

where CCA_L=Culturable command area under Left Main canal (ha); CCA_R=Culturable command area under Right Main canal (ha); CCA_B=Culturable command area under Bhungra canal (ha); p_{ki}= Percentage cropping intensity for each crop i in Kharif season (same percentage value for three canal command areas); p_{ri}= Percentage cropping intensity for each crop i in Rabi season (same percentage value for three canal command areas). Details in this regard are provided in Section 3.3.

4.2.5 Crop Diversion Requirements

Monthly crop diversion requirements CWR_{it} are calculated based on crop water requirements (the water required per hectare of crop activity i times the number of hectares of planted crop activity in that month t for each canal command area) and the overall efficiency. In the absence of any crop activity, CWR_{it} is taken as zero. Water releases from the reservoir must satisfy the irrigation demands of the command area. Details in this regard are provided in Section 5.2.

$$\sum_{i=1}^{12} CWR_{it} A_i - IDL_t = 0; \quad t = 1,....12 \qquad (4.11)$$

$$\sum_{i=13}^{24} CWR_{it} A_i - IDR_t = 0; \quad t = 1,....12 \qquad (4.12)$$

$$\sum_{i=25}^{36} CWR_{it} A_i - IDB_t = 0; \quad t = 1,....12 \tag{4.13}$$

where CWR_{it} =Crop diversion requirements per hectare of crop i in month t (meters).

4.2.6 Canal Capacity Restrictions

The releases for Power House 2 $PH2_t$ and irrigation demand of Left Main canal IDL_t for any month t cannot exceed the Left Main canal capacity CCL. Similarly irrigation demands of Right Main canal and Bhungra canal cannot exceed their respective canal capacities.

$$PH2_t + IDL_t \le CCL; \quad t = 1,....12 \tag{4.14}$$

$$IDR_t \le CCR; \quad t = 1,....12 \tag{4.15}$$

$$IDB_t \le CCB; \quad t = 1,....12 \tag{4.16}$$

where CCL =Maximum canal capacity of Left Main canal (164.44 Mm^3); CCR =Maximum canal capacity of Right Main canal (78.89 Mm^3); CCB =Maximum canal capacity of Bhungra canal (8.40 Mm^3). In the present study, canal capacity is converted into volumetric units i.e., Million cubic meters (Mm^3), so that it becomes compatible with releases from the reservoir. If discharge Q is in cumecs, it can be converted into Mm^3 by multiplying a factor ($Q \times 24 \times 3600 \times 30.4 \times 10^{-6}$). Here, value 24 represents hours per day, 3600 indicates seconds per hour, 30.4 indicates average days in the month and 10^{-6} indicates conversion factor to make m^3 to Mm^3.

4.2.7 Water Requirements for Hydropower Generation

Monthly releases for hydropower production in both Power House 1 and Power House 2 must be greater than the minimum specified value $WR1_t$ and $WR2_t$ for each month *t*. As the downstream requirements, i.e., the share of water for Gujarat is channelized through Power House 2, equality condition is specified in Eq. 4.18. Details in this regard are provided in Sections 5.5 and 5.6.

$$PH1_t \geq WR1_t; \quad t = 1,....12 \tag{4.17}$$

$$PH2_t = WR2_t; \quad t = 1,....12 \tag{4.18}$$

4.2.8 Upstream Requirements

An inter-state bilateral agreement regarding sharing of Mahi water between Rajasthan and Madhya Pradesh was made in the year 1961 (Mahi Bajaj Sagar Report, 1978). Accordingly, it was agreed to reserve 94.39 Mm^3 of Mahi water for upstream utilization ($USMP_t$ in Eqs. 4.2 and 4.3) during the months of November, December and January. Details in this regard are provided in Section 5.5.

4.2.9 Evaporation Losses

Evaporation losses EV_t from the Mahi Bajaj Sagar Reservoir are estimated by Hydrology Directorate of Central Water and Power Commission (Mahi Bajaj Sagar Report, 1978). Details in this regard are provided in Section 5.4.

4.2.10 Minimum and Maximum Areas of Crops

The areas of crops A_i in any season must be greater than or equal to the minimum area $AMIN_i$ and less than or equal to maximum area $AMAX_i$. Details in this regard are provided in Section 3.3.

$$AMIN_i \leq A_i \leq AMAX_i; \quad i = 1,....36 \tag{4.19}$$

where $AMIN_i$=Minimum targeted area for crop of index i (ha); $AMAX_i$=Maximum targeted area for crop of index i (ha). These are fixed based on the existing and projected cropping area in the MBSP command area (MBSP Report on Project Estimate of Unit-II, 2001).

4.2.11 Ground Water Withdrawals

Total monthly ground water withdrawal GW_t in a year should be less than or equal to the estimated annual ground water potential of the aquifer.

$$\sum_{t=1}^{12} GW_t \leq TGW; \quad t = 1, \ldots 12 \tag{4.20}$$

where TGW =Annual ground water potential of the aquifer (31.07 Mm^3/yr).

4.2.12 Live Storage Restrictions

Reservoir storage volume S_t in any month t must be less than or equal to live storage of the reservoir LS .

$$S_t \leq \mathrm{LS}; \quad \mathrm{t} = 1, \ldots 12 \tag{4.21}$$

where LS =Live storage of the reservoir (1829.27 Mm^3).

4.3 SOLUTION TECHNIQUES

Different optimization techniques, namely, RGA, DE, SA, SQ and LP used in the present study (Part 1) are described in the following sections. Comparative analysis of non-traditional optimization techniques with reference to important parameters, search pattern, analogy, status of convergence to optimal, chances of getting stuck in local optima, functions that can be handled and computational time is also made.

4.3.1 Real-coded Genetic Algorithms

Many real world planning problems that are having complex search space are difficult to be solved by traditional techniques. Genetic Algorithms (GA) possess several characteristics that are desirable for these types of problems and make them preferable to traditional optimization techniques (Deb, 1995). GA are based on the mechanics of natural selection and natural genetics. They combine survival of the fittest with a structured but randomized information exchange to form a search algorithm (Goldberg, 1989).

The GA works with an initial population of a string of variables known as chromosomes which hold the parameters or genes and the size of population. The chromosome can be represented using binary code or decimal and accordingly termed as binary coded GA or real-coded GA. The difficulties of using binary coding in a continuous search space are hamming cliff problem, arbitrary precision and fixed coding scheme (Deb and Beyer, 2001). Real-coded GA (RGA) overcomes these difficulties in which the variables are floating point number representation of genes. There are basically three operators namely, selection, crossover, and mutation to generate new population of points from the old population.

In selection operator, a set of chromosomes is selected as initial parents at the reproduction stage on the basis of their fitness, subjected to the constraints posed by the problem. The fittest are given a greater chance of survival as well as greater probability of reproducing more off-springs. The process of mating is implemented through the crossover operator. Mutation, an arbitrary change to the genes, is implemented to preserve the genetic diversity in the population. Its probability of occurrence can be kept low as it can potentially disrupt the good solution. A stochastic selection process biased toward the fitter individuals is implemented to select the new set of population for the next generation. In the present study, tournament selection operator is used for selection of good solutions. The newly-created population is further evaluated and tested for termination to decide the maximum number of generations. If the termination criterion is not met, the population is iteratively operated further by the above three operators and evaluated. One cycle of these operations and its subsequent evaluation is known as a generation. This process is continued until termination criterion of pre-set maximum number of generations is met. The main feature of GA is its ability to operate on many solutions simultaneously, thereby exploring the search space of the objective function thoroughly, which resolves the problem of trapping in local minimum. The pseudo code and flow chart of RGA is presented in Section C-1 of Appendix C.

structured but randomized information exchange to form a search algorithm (Goldberg, 1989).

The GA works with an initial population of a string of variables known as chromosomes which hold the parameters or genes and the size of population. The chromosome can be represented using binary code or decimal and accordingly termed as binary coded GA or real-coded GA. The difficulties of using binary coding in a continuous search space are hamming cliff problem, arbitrary precision and fixed coding scheme (Deb and Beyer, 2001). Real-coded GA (RGA) overcomes these difficulties in which the variables are floating point number representation of genes. There are basically three operators namely, selection, crossover, and mutation to generate new population of points from the old population.

In selection operator, a set of chromosomes is selected as initial parents at the reproduction stage on the basis of their fitness, subjected to the constraints posed by the problem. The fittest are given a greater chance of survival as well as greater probability of reproducing more off-springs. The process of mating is implemented through the crossover operator. Mutation, an arbitrary change to the genes, is implemented to preserve the genetic diversity in the population. Its probability of occurrence can be kept low as it can potentially disrupt the good solution. A stochastic selection process biased toward the fitter individuals is implemented to select the new set of population for the next generation. In the present study, tournament selection operator is used for selection of good solutions. The newly-created population is further evaluated and tested for termination to decide the maximum number of generations. If the termination criterion is not met, the population is iteratively operated further by the above three operators and evaluated. One cycle of these operations and its subsequent evaluation is known as a generation. This process is continued until termination criterion of pre-set maximum number of generations is met. The main feature of GA is its ability to operate on many solutions simultaneously, thereby exploring the search space of the objective function thoroughly, which resolves the problem of trapping in local minimum. The pseudo code and flow chart of RGA is presented in Section C-1 of Appendix C.

A difficulty of the population-based optimizers is that once the search has narrowed near the previous optimal solution, the diversity in the population may not be enough for the search to come out of there and proceed towards the new optimal solution. Deb and Beyer (2001) suggested self-adaptation methodology, an essential feature of natural evolution to minimize this problem. Self-adaptation is a phenomenon which makes genetic algorithms flexible and closer to natural evolution. In the present study of irrigation planning problem, the self-adaptive behavior of real-coded genetic algorithms (RGA) with a simulated binary crossover (SBX) operator and parameter-based mutation operator are explored. The SBX operator (Deb and Agarwal, 1995) uses a probability distribution around two parents to create two children solutions. Unlike other real-parameter crossover operators, SBX uses a polynomial probability distribution which is similar in principle to the probability of creating children solution in crossover operators used in binary coded GA. The value of distribution index for SBX controls the distance of the children solutions from the parents. A small value of distribution index allows solutions far away from parents to be created as children solutions and a large value restricts only near parent solutions to be created as children solutions. Similarly, the distribution index for parameter based mutation decides the effect of perturbance in the parent solutions.

There are two aspects which give RGA with SBX their self-adaptive power: (i) children solutions closer to parent solutions are more likely to be created, and (ii) the span of children solutions is proportional to the span of parent solutions. Both the properties are essential for a crossover operator to exhibit self-adaptive behavior in GA. This is because with these properties the diversity in children solutions is directly controlled by the diversity in parent solutions. Movement of the parent population in the search space is dictated by the fitness function through the selection operator. This selection operator i.e., SBX crossover allows GA to search a region near the parent population which exhibits self-adaptation. The population size (POP), crossover probability (XR) and mutation probability (MUT) are the three important parameters which governs the successful working of the RGA. More details on RGA are available in Goldberg (1989), Deb (1995), Deb (1999) and Deb (2001).

4.3.2 Differential Evolution

Differential Evolution (DE) is an improved version of GA and uses real coding of floating point numbers. The advantages of DE are its simple structure, ease of use, speed, robustness and chances of getting global optimum (Price and Storn, 1997).

DE is a population based search technique which utilizes NP as population of D dimensional parameter vectors for each generation. The initial population is chosen randomly if no information is known about the problem. In case a preliminary solution is available, the initial population is often generated by adding normally distributed random deviations to the nominal solution. The basic idea behind DE is a new scheme for generating trial parameter vectors. DE generates new parameter vectors by adding the weighted difference vector between two population members to a third member. If the resulting vector yields a lower objective function value than a predetermined population member, the newly generated vector replaces the vector with which it was compared. In addition, the best parameter vector is evaluated for every generation in order to keep track of the progress that is made during the minimization process. Extracting distance and direction information from the population to generate random deviations result in an adaptive scheme with excellent convergence properties.

DE maintains two arrays, each of which holds a population of NP, D dimensional, real valued vectors. The primary array holds the current vector population, while the secondary array accumulates vectors that are selected for the next generation. In each generation, NP competitions are held to determine the composition of the next generation. Every pair of vectors (X_a, X_b) defines a vector differential: $(X_a - X_b)$. When X_a and X_b are chosen randomly, their weighted differential is used to perturb another randomly chosen vector X_c. This process can be mathematically expressed as:

$$X_c' = X_c + F(X_a - X_b) \quad (4.22)$$

The weighting factor or scaling factor F is a user supplied constant in the optimal range of 0.5 to 1.0 (Price and Storn, 2005). In every generation, each primary array vector X_i is targeted for crossover with a vector like X_c' to produce a trial vector X_t. Thus, the trial vector is the child of two parents, a noisy random vector and the target vector against which it must compete. Non-uniform crossover is used with a Crossover Constant CR, in the optimal range of 0.5 to 1.0 (Price and Storn, 2005) which actually represents the probability that the child vector inherits the parameter values from the noisy random vector. When CR=1, for example, every trial vector parameter is certain to come from X_c'. On the other hand, if CR=0, all but one trial vector parameter comes from the target vector. To ensure that X_t differs from X_i by at least one parameter, the final trial vector parameter always comes from the noisy random vector even when CR=0. Then the cost of the trial vector is compared with that of the target vector, and the vector that has the lowest cost of the two would survive for the next generation. This process is continued until termination criterion of preset maximum number of generations is met and difference of function values between two consecutive generations reaches a small value. In all, three factors control evolution under DE, the population size NP, the weight applied to the random differential F and the crossover constant CR. The pseudo code and flow chart of DE is presented in Section C-2 of Appendix C.

Different strategies can be adopted in DE algorithm depending upon the type of problem for which it is applied. The strategies can vary based on the vector to be perturbed, number of difference vectors considered for perturbation, and finally the type of crossover used. Price and Storn (1997) gave the working principle of DE with single strategy DE/rand/1/bin. Later, they added nine more different strategies namely, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp (Price and Storn, 2005). Here, DE/x/y/z indicates DE for Differential Evolution, x represents a string denoting the vector to be perturbed (rand: random vector; best: best vector), y is the number of difference vectors considered for perturbation of x and z stands for the type of crossover being used (exp: exponential; bin: binomial).

The working algorithm outlined above is for the strategy DE/rand/1/bin. Hence the perturbation can be either in the best vector of the previous generation or in any randomly chosen vector. Similarly, for perturbation, either single or two vector differences can be used. For perturbation with a single vector difference, out of the three distinct randomly chosen vectors, the weighted vector differential of any two vectors is added to the third one. Similarly, for perturbation with two vector differences, five distinct vectors, other than the target vector are chosen randomly from the current population. Out of these, the weighted vector difference of each pair of any four vectors is added to the fifth one for perturbation. A strategy that is found to be suitable for a given planning problem may not work well when applied for a different problem. In the present study, all ten strategies of DE are employed. Careful selection of strategy and parameters is essential for the meaningful analysis of the problem. However, extensive sensitivity analysis is required to assess the robustness of the methodology. More details regarding DE are available in Price and Storn (1997), Onwubolu and Babu (2004) and Price and Storn (2005).

4.3.3 Simulated Annealing

Simulated Annealing (SA) solution methodology resembles the cooling process of molten metals through annealing. At high temperature, the atoms in the molten metal can move freely with respect to each other, but as the temperature is reduced, the movement of the atoms gets restricted. The atoms start to get arranged and finally form crystals having the minimum possible energy. However, the formation of the crystal mostly depends on the cooling rate (CoR). If the temperature is reduced at a very fast rate, the crystalline state may not be achieved at all and instead, the system may end up in a polycrystalline state, which may have a higher energy state than the crystalline state. Therefore, in order to achieve the absolute minimum energy state, the temperature needs to be reduced at a slow rate. The process of slow cooling is known as annealing process.

SA procedure simulates the above process of slow cooling of molten metals to achieve the minimum function value in a minimization problem. The cooling phenomenon is simulated by controlling a parameter, namely, temperature T introduced with the concept of the Boltzmann probability distribution. According to the Boltzmann probability distribution, a system in thermal equilibrium at a temperature T has its energy distributed probabilistically according to $P(E) = e^{(-E/k_b T)}$, where E is the energy of the system and k_b is the Boltzmann constant. This expression indicates that a system at a high temperature has almost uniform probability of being at any energy state, but at a low temperature it has a small probability of being at a high energy state. Therefore, by controlling the temperature T and assuming that the search process follows the Boltzmann probability distribution, the convergence of an algorithm can be controlled. Metropolis (Kirkpatrick, 1983) suggested a way to implement the Boltzmann probability distribution in simulated thermodynamic systems which can also be used in the function minimization context. For example, at any instant the current point is $x(t')$ and the function value at that point is $E(t') = f(x(t'))$. Using the Metropolis algorithm, the probability of the next point being at $x(t'+1)$ depends on the difference in the function values at these two points or $\Delta E = E(t'+1) - E(t')$. Probability value $P(E(t'+1))$ is calculated using the Boltzmann probability distribution:

$$P(E(t'+1)) = \min\left(1, e^{(-\Delta E/k_b T)}\right) \tag{4.23}$$

If $\Delta E \leq 0$, the above probability is one and the point $x(t'+1)$ is always accepted. In the function minimization context, this is meaningful because if the function value at $x(t'+1)$ is better than at $x(t')$, the point $x(t'+1)$ must be accepted. When $\Delta E > 0$, which implies that the function value at $x(t'+1)$ is worse than that at $x(t')$. According to the Metropolis algorithm, there is some finite probability of selecting the point $x(t'+1)$ even though it is worse than the point $x(t')$. This probability depends on relative magnitude of ΔE and T values. If the parameter T is large, this probability is more or less high for points with largely different function values. Thus, any point is almost acceptable for a large value of T. On the other hand, if the parameter T is small, the probability of accepting an arbitrary point is small. Thus, for small values of T, the points with only small deviation in function value are accepted. In order to simulate the thermal equilibrium at every temperature, a number of iterations (NI) are performed at a particular temperature, before reducing the temperature. The algorithm is terminated when a sufficiently small temperature is obtained and a small enough change in function values is found. The pseudo code and flow chart of SA is presented in Section C-3 of Appendix C. The initial temperature (T), cooling rate (CoR) and number of iterations (NI) performed at a particular temperature are the three important parameters which governs the successful working of the simulated annealing procedure. More details regarding SA are available in Ingber (1993), Deb (1995) and Rao (2003).

4.3.4 Simulated Quenching

Simulated Quenching (SQ) solution methodology is an extension of Simulated Annealing, but computationally faster (Ingber, 1993). The algorithm and the analogy of the technique remains the same as that of SA except for the annealing schedule. SA slowly reduces the temperature of the solution, thus gradually reducing the probability of accepting a move to a higher energy state. On the other hand, SQ reduces the temperature in the system and brings it to a minimum temperature quickly. The process is terminated when a sufficiently small temperature is obtained and a small enough change in function values is found. The pseudo code and flow chart of SQ is presented in Section C-3 of Appendix C.

4.3.5 Linear Programming

Linear Programming (LP) deals with the problem of allocating limited resources among competing activities in an optimal manner (Maji and Heady, 1980; Rao, 2003). In a more convenient matrix notation, a typical LP problem can be written as

$$MAX/(MIN) \quad Z = C^{T}X \tag{4.24}$$

subject to the constraints

$$AX \leq B \quad (4.25)$$

and

$$X \geq 0 \quad (4.26)$$

where C is an (n x 1) vector of known constants, X is an (n x 1) vector of decision variables, A is a (m x n) matrix of known constants and B is a (m x 1) vector of constants. The problem is to find a set of X, that maximize (or minimize) the objective function Z (Eq. 4.24) and satisfy the constraints (Eqs. 4.25 and 4.26).

A comparison of the above four non-traditional algorithms, namely, RGA, DE, SA and SQ is presented in the Table 4.1.

Table 4.1 A comparative analysis of non-traditional optimization techniques employed in the present study

	RGA	DE	SA	SQ
Important Parameters	Number of generations, population size, crossover probability, mutation probability	Number of generations, population size, strategy, crossover constant, weighting factor	Number of iterations, initial temperature, final temperature, cooling rate	Number of iterations, initial temperature, final temperature, cooling rate
Search Pattern	Population-based	Population-based	Point-by-point	Point-by-point
Analogy	Darwinian survival of the fittest	Darwinian survival of the fittest	Annealing process of metal	Annealing process of metal
Status of convergence to optimal	Near optimal	Near optimal	Near optimal	Near optimal
Chances of getting stuck in local optima	Minimum	Minimum	Almost negligible	Higher than minimum
Functions that can be handled	Non-differentiable, nonlinear, multimodal, functions having complex search space with many local optimal solutions			
Computational Time	Low	Very low	Very high	High

4.4 PERFORMANCE EVALUATION OF IRRIGATION SYSTEMS

It has been observed that the performance of many irrigation projects is very poor with the result that the intended benefits under the projects have not been fully realized (Raju and Pillai, 1999). The methodology is aimed to identify components that affect the system performance and formulate guidelines for other existing irrigation systems. The scope of each performance criterion is not limited. It may have overlapping effect on the other criteria also (Raju and Duckstein, 2002). In the present study seven performance criteria are analyzed in multicriterion context for sixteen irrigation subsystems of Mahi Bajaj Sagar Project, Rajasthan, India. Information about seven criteria is described below.

Criterion 1: Land Development Works (LDW)

Land Development Works includes land leveling, land shaping and consolidation of holdings.

Criterion 2: Timely Supply of Inputs (TSI)

Efficient and timely use of irrigation facilities requires farmer's knowledge about the technology, developments in irrigated agriculture, timely supply of inputs such as seeds, fertilizers, and other resources.

Criterion 3: Conjunctive Use of Water resources (CUW)

Conjunctive use of surface and ground water is essential to provide more reliable supply of water to crops when needed. This also reduces water logging effect, if any.

Criterion 4: Participation of Farmers' (PF)

Participation of farmers' is essential for the optimum utilization of resources, which also determines the success of an irrigation project.

Criterion 5: Economic Impact (EI)

The economic impact is assessed by the economic status of the individual farmer or group of farmers'.

Criterion 6: Crop PRoductivity (CPR)

Crop productivity can be assessed by knowing the yield of the crop in the command area.

Criterion 7: Environmental Conservation (EC)

Environmental conservation issues analyzed after introduction of irrigation facilities are ground water table and salinity level.

All these criteria are assessed subjectively for sixteen irrigation subsystems of MBSP due to lack of precise numerical data. However, these subjective data are converted into numerical scale for the analysis. The analysis is explained in Chapter 5 and Part 2 of Chapter 6.

4.5 KOHONEN ARTIFICIAL NEURAL NETWORKS (KANN)

An Artificial Neural Network (ANN) is a massively parallel distributed information processing system that has certain performance characteristics resembling biological neural networks of the human brain. Artificial neural networks can be used for performing general mapping from input pattern (space) to output pattern (space), grouping similar pattern and so on (Thirumalaiah and Deo, 1998). In the present study Kohonen based classification methodology is employed for grouping the alternatives. The methodology is briefly described as follows:

KANN is a self-organizing mapping technique with only two layers, input and output. Each layer is made up of neurons. The number of neurons in input layer, *M*, is identical to the dimensionality of input vectors while the number of neurons in the output layer, *N*, is determined by the number of groups that input data will be partitioned into. Each neuron in the output is fully interconnected with those in input layer by a set of weights or a weight vector, e.g., the j th output neuron has a weight vector connecting to input neurons, $w_j = \{w_{ji}\}, i = 1,2,....M$. The function of an input neuron is to transmit input data to the next layer, whereas an output neuron calculates the Euclidean distance between its weight vector w_j and input vector X' to measure their similarity. The main objective of

Kohonen network is to transform an incoming vector with arbitrary dimension into a one or two dimensional discrete map, and to perform this transformation adaptively in a topologically ordered fashion (Liong *et al*, 2004; Raju *et al*, 2005). The Kohonen neural network training procedure is as follows:

1. Assign randomly small values to the initial weight vectors $w_j(0)$ of output neuron j, where $j = 1, 2, \ldots, N$.
2. Draw an input vector X' randomly from the input data, and feed it into the Kohonen network.
3. Find distance D_j between input vector X' and each output neuron's weight $w_j(n)$ at time n.

   $D_j = \|X' - w_j\|; j = 1,2,\ldots, N..where\ \|\ \|$ is Euclidean norm.
4. Select the winning neuron C' which has minimum of D_j.

   $C' = \arg_j \min(D_j); j = 1,2,\ldots\ldots N$
5. Adjust the weight vectors of all neurons through

   $w_j(n+1) = w_j(n) + \eta(n)[X'(n) - W_j(n)] if \in A'_c$

   $w_j(n+1) = w_n(n)$ otherwise

   $C' = \arg_j \min(D_j); j = 1,2,\ldots\ldots N$

where, $\eta(n)$ is the learning rate parameter which controls how fast the algorithm can change and update their internal parameters in response to new data or can minimize their error while learning. A'_C is the neighborhood function centered on the winning neuron C'. Repeat steps 2 to 5 until no noticeable changes are observed or when the specified number of epochs (iterations) is achieved.

In the present study, KANN is used to classify the irrigation subsystems. MATLAB-based-solution-methodology is employed. Built-in functions such as NEWC which is a function of NET (creates new competitive layer which includes provision of giving learning rate and conscience rate values) is used. Conscience bias learning function is used to increase the net input to neurons that have the lowest average output until each neuron responds approximately an equal percentage of the time. Learning is done using a parameter conscience rate. Default values of learning rate and conscience rate used are 0.01 and 0.001 respectively (http://www.mathworks.com/access/helpdesk/help/toolbox/nnet). TRAIN function (includes function NET and input vector) and SIM (simulating the network) are also used (http://www.mathworks.com). Detailed description of KANN is available in Kohonen (1989), Kulkarni and Kiang (1995) and Liong *et al* (2004).

4.6 MULTICRITERION DECISION MAKING TECHNIQUES

Multicriterion Decision Making (MCDM) techniques are gaining importance due to their inherent ability to judge different alternative scenarios for possible selection of best strategy which may be further analyzed for its final implementation (Szidarovszky *et al*, 1986; Pomerol and Romero, 2000). In this study, three MCDM techniques namely, MCQA-2, MAUT, and CP are employed to rank the grouped irrigation subsystems after KANN analysis. Also, AHP is employed to determine the weights of the performance criteria. Spearman Rank Correlation technique is employed to estimate the correlation coefficient values. These techniques are discussed in detail in the following sections.

4.6.1 Multicriterion Q-Analysis-2

Multicriterion Q-Analysis-2 (MCQA-2) approach is based on multidimensional graph theory (Johnson, 1981). It is a technique by which many alternatives can be compared simultaneously with respect to a set of criteria. The essence of MCQA-2 is to establish a preference matrix (U') derived from payoff matrix. The methodological steps are (Hiessl *et al*, 1985; Duckstein and Nobe, 1997):

1) Preference matrix (U') is transformed into an incidence matrix $[T(s')]$ using a slicing level $\alpha(s')$.

$$t(a,j) = 1 \text{ if } u'(a,j) \geq \alpha(s')$$
$$= 0 \text{ if } u'(a,j) < \alpha(s') \qquad (4.27)$$

where $t(a,j)$ and $u'(a,j)$ are elements of incidence and preference matrices for alternative a and criterion j.

2) Shared face matrix can be calculated as $[T(s') \times T(s')^{tr}] - \mathrm{I}$, where tr is the transpose operator and I is the matrix of unity. All the necessary information is in the upper triangular portion of the shared face matrix and called as Q-vector. Reading across a row or down a column associated with an element provides a measurement of the connectivity of that element with the other elements.

MCQA-2 reduces an MCDM problem to a trade off between three conflicting indices: Project Satisfaction Index (PSI), Project Concordance Index (PCI) and Project Discordance Index (PDI) for each alternative a. These three indices can be calculated based on the number of slicing levels $\alpha(s'), s' = 1,2,....S$ (Raju and Nagesh Kumar, 2001).

Project Satisfaction Index (PSI) is defined as

$$PSI(a) = \alpha(1).V(a,1) + .. + \alpha(s').V(a,s') + ... + \alpha(S).V(a,S) \tag{4.28}$$

where $V(a,s')$ is the sum of the weights corresponding to the criteria for each alternative a satisfied at level s'.

Project Concordance Index (PCI) is based on the q-connectivity between the various alternatives. If $q_{max}(a,s')$ is the highest q-level of alternative a and $q_{min}(a,s')$ is the level at which a is for the first time in the same equivalence class as another alternative, then

$$\Delta q(a,s') = q_{max}(a,s') - q_{min}(a,s') \tag{4.29}$$

Then $PCI(a)$ for alternative a is

$$PCI(a) = \alpha(1).\Delta q(a,1) + .. + \alpha(s').\Delta q(a,s') + .. + \alpha(S)\Delta q(a,S) \tag{4.30}$$

Project Discordance Index (PDI) is defined in a similar way as PCI using complimentary incidence matrix $\widetilde{T}(s') = 1 - T(s')$. Then PDI of alternative a is

$$PDI(a) = \alpha(1).\Delta\widetilde{q}(a,1) + .. + \alpha(s').\Delta\widetilde{q}(a,s') + .. + \alpha(S)\Delta\widetilde{q}(a,S) \tag{4.31}$$

where $\Delta\widetilde{q}(a,s')$ is defined as

$$\Delta\widetilde{q}(a,s') = \widetilde{q}_{max}(a,s') - \widetilde{q}_{min}(a,s') \tag{4.32}$$

PSI, PCI, PDI for each alternative a can be normalized by the highest values PSIMAX, PCIMAX, PDIMAX that can be expected to be taken by PSI, PCI, PDI and denoted as PSIN, PCIN and PDIN. The normalized values are combined through an L_p - metric approach. The total priority of each alternative a is

$$L_p(a) = \left[|1 - PSIN(a)|^p + |1 - PCIN(a)|^p + |PDIN(a)|^p \right]^{1/p} \qquad (4.33)$$

The flow chart for working of MCQA-2 is presented in Fig. D-1 of Appendix D.

4.6.2 Multi Attribute Utility Theory

Multi Attribute Utility Theory (MAUT) takes into consideration the decision maker's preferences in the form of utility functions which are defined over a set of attributes (or criteria) (Goicoechea *et al*, 1982). The utility value for each alternative can be determined in two phases as follows:

1) Verification of preferential and utility independence conditions

A pair of attributes (x_1, x_2) is preferentially independent of the other attributes $(x_3, \ldots\ldots, x_j)$ if preference between (x_1, x_2) given that $(x_3, \ldots\ldots, x_j)$ are held fixed, irrespective of the level at which these $(x_3, \ldots\ldots, x_j)$ are fixed. Attribute x_1 is utility independent of other attributes $(x_2, \ldots\ldots, x_j)$ if preferences among possibilities over x_1 given $(x_2, \ldots\ldots, x_j)$ are fixed and do not depend on the level where those attributes are fixed (Goicoechea *et al*, 1982).

2) Derivation of the single and multi attribute utility function

The values of utilities vary between zero and one. In the present study, these are assumed as linear. By fixing utility of best value (highest values in the payoff matrix for that attribute) U_{best} as 1 and worst value (lowest values in the payoff matrix for that attribute) U_{worst} as 0, the utility value varies linearly between 0 to 1 for intermediate values in the payoff matrix. These intermediate values give points on the utility curve.

The utility functions are of two types. The first type assumes the decision maker's overall utility function is additively separable (Eq. 4.34) and the other is multiplicatively separable (Eq. 4.35) with respect to the single attribute utility functions.

Additive model

$$u(x_1, x_2, ..., x_j) = k_1 u_1(x_1) + k_2 u_2(x_2) + ... + k_j u_j(x_j) \tag{4.34}$$

Multiplicative model

$$1 + ku(x_1, x_2, ..., x_J) = \prod_{j=1}^{J} \left[1 + kk_j u_j(x_j)\right] \tag{4.35}$$

where

k	=	Overall scaling constant ($-1 < k < 0$ indicates risk aversive attitude of the decision maker whereas $k > 0$ indicates risk seeking attitude)
k_j	=	Scaling constant for attribute j (between 0 to 1)
$u(.)$	=	Overall utility function operator (between 0 to 1)
$u_j(.)$	=	Utility function operator for each attribute j (between 0 to 1)

The flow chart for working of MAUT is presented in Fig. D-2 of Appendix D. Detailed procedure of finding the single attribute utility function(s) and multi attribute utility function is discussed in Part 2 of Chapter 6.

4.6.3 Compromise Programming

Compromise Programming (CP) defines the 'best' solution as the one in the set of efficient solutions whose point is at the least distance from an ideal point (Zeleny, 1982). The aim is to obtain a solution that is as 'close' as possible to some 'ideal'. The distance measure used in Compromise Programming is the family of L_p - metrics and given as

$$L_p(a) = \left[\sum_{j=1}^{J} w_j'^p \left|f_j^* - f(a)\right|^p\right]^{\frac{1}{p}} \tag{4.36 (a)}$$

If the criteria are not expressed in commensurable terms, then a scaling function $(M_j - m_j)$ can be defined to ensure the same range for each criterion and this range corresponds to the interval (0, 1). With this transformation, Eq. 4.36 (a) becomes,

$$L_p(a) = \left[\sum_{j=1}^{J} w_j'^p \left| \frac{f_j^* - f(a)}{M_j - m_j} \right|^p \right]^{\frac{1}{p}} \qquad (4.36\text{ (b)})$$

$L_p(a)$ = L_p - metric for alternative a, $f(a)$ = Value of criterion j for alternative a, M_j = Maximum value of criterion j in set A', m_j = Minimum value of criterion j in set A, f_j^* = Ideal value of criterion j, w_j' = Weight of the criterion j, p = Parameter reflecting the attitude of the decision maker with respect to compensation between deviations. For p=1, all deviations from f_j^* are taken into account in direct proportion to their magnitudes meaning that there is full (weighted) compensation between deviations. For $p = \infty$, the largest deviation is the only one taken into account corresponding to zero compensation between deviations. The flow chart for working of CP is presented in Fig. D-3 of Appendix D.

4.7 ANALYTIC HIERARCHY PROCESS

Analytic Hierarchy Process (AHP) is used to estimate weights of the criteria (Saaty and Gholamnezhad, 1982; Karamouz *et al*, 2002). The technique deals with performance of multiple criteria simultaneously. The methodology is capable of

(a) breaking down a complex, unstructured situation into its component parts,

(b) arranging these parts or variables into a hierarchic order,

(c) assigning numerical values 1 to 9 to subjective judgements on the relative importance of each criterion (1=equally important or preferred; 3=slightly more important or preferred; 5=strongly more important or preferred; 7=very strongly more important or preferred; 9=extremely more important or preferred; 2, 4, 6, 8=intermediate values to reflect compromise; reciprocals used to reflect dominance of the second alternative as compared with the first) and

(d) synthesizing the judgments to determine the overall priorities of the criteria.

Eigenvector approach is used to compute the priorities of the criteria for the given pairwise comparison matrix. The eigenvector corresponding to maximum eigen value (λ_{max}) is computed using power technique. Since small changes in elements of pairwise comparison matrix imply a small change in λ_{max} the deviation of the latter from matrix size N' is a deviation of consistency. This is represented by $[(\lambda_{max} - N')/(N'-1)]$ and termed as Consistency Index (CI). Random Index (RI) is the consistency index of the random matrix obtained by calculating consistency index for a randomly filled matrix of size N'. The ratio of CI to average RI for the same order matrix is called the Consistency Ratio (C_R). A consistency ratio value of 0.1 or less is considered acceptable (Saaty, 1990).

4.8 SPEARMAN RANK CORRELATION TECHNIQUE

Spearman Rank Correlation (SRC) technique is useful to determine the measure of association between ranks obtained by different MCDM techniques. If U_a and V_a denote the ranks achieved by two different MCDM techniques for the same alternative *a*, then SRC coefficient (*R*) (Gibbons, 1971; Raju and Nagesh Kumar, 1999) is

$$R = 1 - \frac{6\sum_{a=1}^{A'} D_a^{2}}{A'(A'^{2} - 1)} \qquad (4.37)$$

where

D_a	=	Difference between ranks U_a and V_a achieved by the same alternative *a*
A'	=	Number of alternatives
R	=	1 represents perfect association between the ranks
R	=	0 represents no association between the ranks
R	=	-1 represents perfect disagreement between the ranks

The next chapter describes the estimation of necessary parameters such as crop diversion requirements, monthly inflows into the reservoir, evaporation losses, upstream and downstream requirements, gross and net returns from the crops, weights of the criteria that are required in the mathematical model for irrigation planning, KANN methodology and MCDM techniques.

CHAPTER 5

PARAMETER ESTIMATION FOR THE MATHEMATICAL MODELING OF THE CASE STUDY

5.1 GENERAL

The estimation of the following parameters is required in the mathematical, Kohonen Artificial Neural Networks (KANN) and Multicriterion Decision Making (MCDM) modeling of Mahi Baja Sagar Project (MBSP). These are explained in detail in the following sections.

5.2 ESTIMATION OF CROP DIVERSION REQUIREMENTS

The water requirements of a crop is expressed as the depth of water needed to meet the water loss through Reference Evapotranspiration (ET_o) of disease free crop, growing in large fields under non-restricting soil conditions and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977; Patra, 2002). Reference Evapotranspiration is determined by the Penman Monteith technique based on the meteorological data of Banswara station representing MBSP (Table 3.3). CROPWAT software developed by Food and Agriculture Organization (FAO) for Penman Monteith technique is used in the present analysis for computation of ET_o, there by crop water requirements (http://www.fao.org/waicent/faoinfo/agricult/agl/aglw/cropwat.stm, Allen *et al*, 1998). Crop Evapotranspiration (ET_c) or crop water requirements is calculated by multiplying the ET_o by a crop coefficient k_c.

$$ET_c = k_c . ET_o \tag{5.1}$$

The crop duration and crop coefficients used in the present study are based on crop characteristics, time of planting or sowing, stages of crop development and general climatic conditions (Doorenbos and Pruitt, 1977; Allen *et al*, 1998; Singh *et al*, 2001) and interaction, personal discussion with project officials and experts (Krishna Rao, 2003; Palanisamy, 2004). ET_c for each crop is determined by multiply the respective crop coefficients with ET_o. The monthly values of the crop diversion requirements are shown in Table 5.1. Crop diversion requirements CWR_{it} used in the planning model is based on overall efficiency of 50% i.e. ratio of crop water requirements to overall efficiency (Bansal, 2003).

5.3 MONTHLY INFLOWS INTO THE RESERVOIR

Fourteen years of historical inflow data (MBSP Inflows Record, 2000) is used to obtain the various dependability levels of inflow into the MBSP. These are computed based on Weibull plotting position formulae (Patra, 2002). Fig. 5.1 presents the inflow values from June to October for various dependable inflow levels (α') which were used in the irrigation planning model. The inflows of other months are not significant and are neglected. It is observed from Fig. 5.1 that there is wide variation in the inflow values for various dependable inflow levels 50% (summation of inflow values from June to October are 5448.01 Mm^3) to 90% (summation of inflow values from June to October are 1160.36 Mm^3). In the present study, 75% dependable inflow level is employed for MBSP which is amounting to 2880.93 Mm^3 (Maji and Heady, 1980; MBSP Report on Status June 2002 at a Glance, 2002).

5.4 EVAPORATION LOSSES FROM THE RESERVOIR

Evaporation losses from the Mahi Bajaj Sagar Reservoir are estimated by Hydrology Directorate of Central Water and Power Commission (Mahi Bajaj Sagar Report, 1978). These are presented in Table 5.2.

Table 5.1 Monthly crop diversion requirements (meters)

MONTH	ET_o (mm/day)	Maize	Paddy	Cotton	Pulses	Sugar Cane	Zaid Crop	Wheat	Barley	Gram	Barseen	Mustard	Fruits & Veg.
January	3.25	0.00	0.00	0.00	0.00	0.21	0.00	0.23	0.23	0.21	0.21	0.07	0.07
February	4.14	0.00	0.00	0.00	0.00	0.19	0.00	0.24	0.23	0.23	0.23	0.06	0.06
March	5.57	0.00	0.00	0.00	0.00	0.21	0.00	0.09	0.07	0.03	0.03	0.03	0.06
April	4.13	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.03
May	7.76	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	6.81	0.15	0.25	0.08	0.09	0.39	0.01	0.00	0.00	0.00	0.00	0.00	0.00
July	5.57	0.30	0.35	0.15	0.30	0.35	0.05	0.00	0.00	0.00	0.00	0.00	0.00
August	4.88	0.36	0.34	0.28	0.35	0.32	0.02	0.00	0.00	0.00	0.00	0.00	0.00
September	4.57	0.31	0.30	0.33	0.25	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
October	4.39	0.11	0.24	0.33	0.01	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
November	2.09	0.00	0.00	0.13	0.00	0.13	0.00	0.05	0.02	0.03	0.03	0.01	0.02
December	3.07	0.00	0.00	0.13	0.00	0.20	0.00	0.19	0.16	0.13	0.13	0.03	0.05
Total	56.23	1.24	1.47	1.42	1.00	3.08	0.09	0.79	0.72	0.63	0.63	0.21	0.29

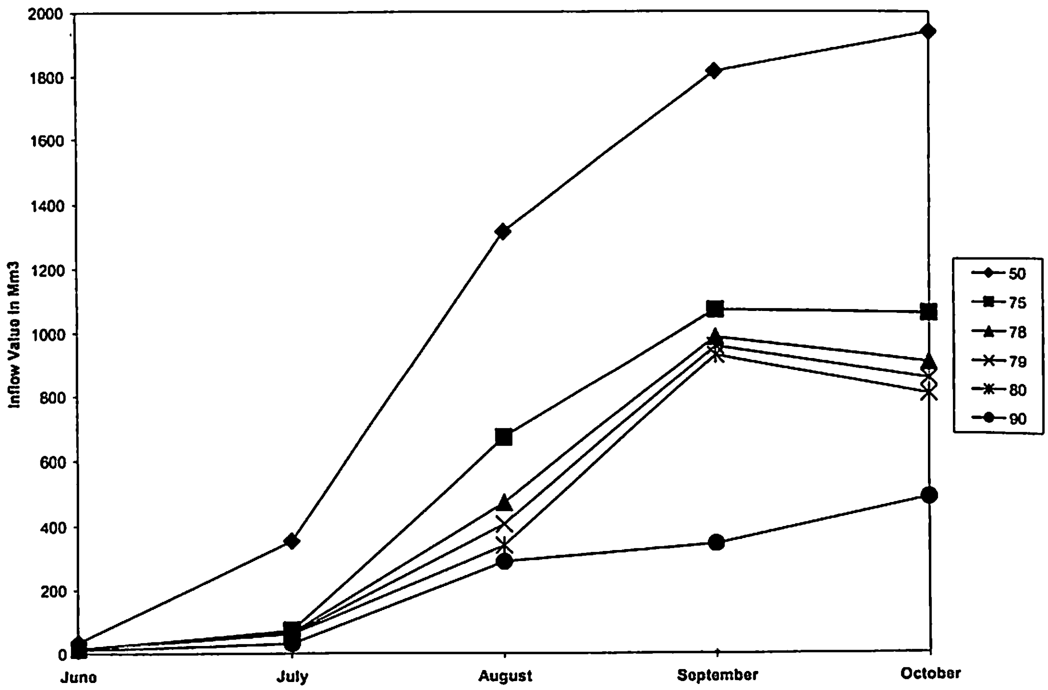

Fig. 5.1 Monthly inflows into reservoir of MBSP at different dependability level α'

(Source: MBSP Inflows Record, 2000)

Table 5.2 Monthly evaporation losses EV_t (Mm^3)

(Source: Mahi Bajaj Sagar Report, 1978)

Month	Evaporation Losses
January	20.69
February	32.31
March	26.86
April	32.31
May	39.57
June	30.49
July	22.14
August	19.24
September	21.42
October	24.68
November	22.51
December	19.24
Total	311.46

5.5 UPSTREAM AND DOWNSTREAM REQUIREMENTS

An inter-state bilateral agreement is made between states of Rajasthan and Madhya Pradesh in the year 1961. Accordingly it was agreed to reserve 368.11 Mm^3 of Mahi water for upstream utilization in Madhya Pradesh. As the places of utilization are very near to the periphery of the Mahi Bajaj Sagar reservoir, it is expected that 84.95 Mm^3 water can flow back into the reservoir as regenerated water during the months of November, December and January (28.32 Mm^3 each) resulting in net share of Madhya Pradesh to be 283.17 Mm^3 (Mahi Bajaj Sagar Report, 1978). Similar agreement is made between Rajasthan and Gujarat in the year 1966 regarding the sharing of Mahi water. It was agreed to release 1132.67 Mm^3 of water to downstream Gujarat through power house 2 (inclusive of evaporation loss). This includes actual requirements ($12\times81.14=973.68$ Mm^3 as mentioned in Table 5.3) and evaporation losses. The monthly upstream requirements of Madhya Pradesh and downstream requirements to Gujarat are presented in Table 5.3.

Table 5.3 Monthly upstream and downstream requirements from Mahi Bajaj Sagar Project (Mm^3)

(Source: Mahi Bajaj Sagar Report, 1978)

Month	Upstream requirement of Madhya Pradesh excluding Regeneration (Mm^3)	Downstream requirement of Gujarat excluding Evaporation Losses (Mm^3)
January	94.39	81.14
February	0.00	81.14
March	0.00	81.14
April	0.00	81.14
May	0.00	81.14
June	0.00	81.14
July	0.00	81.14
August	0.00	81.14
September	0.00	81.14
October	0.00	81.14
November	94.39	81.14
December	94.39	81.14
Total	283.17	973.68

5.6 HYDROPOWER REQUIREMENTS

The Mahi Bajaj Sagar Project includes a dam, a system of canals and two hydroelectric power houses, Power House 1 (*PH 1*) located near Banswara with installed capacity of 2x25 MW and Power House 2 (*PH 2*) near Lilvani village of installed capacity 2x45 MW. In case of *PH 1* average head has been taken as 40 m (Mahi Bajaj Sagar Report, 1978) and discharge is calculated according to the power generation $WR1_t$ used in the planning model (Mahi Hydel Project Report, 2003) and is presented in Table 5.4. For example, power generation for the month of January is 13.32 MW. Discharge Q is computed from relation $P = \gamma QH$, where P=Power produced (13.32×10^6 Watts); γ=Unit weight of water (9810 N/m^3); Q is the discharge requirements through turbines (m^3/sec); H=Average head (40m). From this, Q is computed and converted to 88.41 Mm^3 as per the procedure explained in Section 4.2.6. The share of Gujarat state is channelized through *PH 2* (http://www.rajirrigation.gov.in/4mahi.htm). In case of *PH 2*, monthly releases ($WR2_t$ used in the planning model) are 81.14 Mm^3 (Table 5.3) in the hydel canal, i.e., LMC (Mahi Bajaj Sagar Report, 1978). The project is basically planned to meet irrigation requirements and power generation is incidental.

Table 5.4 Monthly power generation and corresponding discharge requirements for *PH 1* (Source: Mahi Hydel Project Report, 2003)

Month	Power Generation (MW)	Discharge (Mm^3)
January	13.32	88.41
February	14.30	94.91
March	10.80	71.68
April	9.52	63.18
May	8.80	58.41
June	8.24	54.69
July	7.44	49.38
August	7.82	51.90
September	10.68	70.88
October	14.70	97.56
November	15.30	101.55
December	15.55	103.21
Total	136.47	905.76

5.7 GROSS AND NET RETURNS FROM THE CROPS

The gross returns, seeds cost, fertilizer cost, irrigation charges for crops grown in the command area are obtained from MBSP Report on Project Estimate of Unit-II (2001). Expenditure on hired labour and plant protection has been taken as Rs.1070 per ha and Rs.400 per ha respectively, for irrigated areas. These are presented in Table 5.5. The net returns of each crop per hectare are obtained by deducting the costs of seed, fertilizer, hired labour, irrigation and plant protection from gross returns.

Table 5.5 Net returns (B_i) of various crops grown in the command area (in Rupees)

(Source: MBSP Report on Project Estimate of Unit-II, 2001)

S.No.	Crop	Gross Returns Per ha	Seeds Cost Per ha	Fertilizer Cost Per ha	Hired Labour Cost Per ha	Irrigation Charges Per ha	Plant Protection Charges Per ha	Net Returns Per ha
1.	Maize (K)	9000	1000	1200	1070	90	400	5240
2.	Paddy (K)	15750	750	1000	1070	200	400	12330
3.	Cotton (K)	25500	400	1450	1070	180	400	22000
4.	Pulses (K)	12800	350	900	1070	105	400	9975
5.	Sugarcane (K)	30000	4000	2500	1070	100	400	21930
6.	Zaid Crop (K)	14400	350	900	1070	290	400	11390
7.	Wheat (R)	23400	2200	1400	1070	150	400	18180
8.	Barley (R)	10400	1000	1000	1070	105	400	6825
9.	Gram (R)	23340	900	1000	1070	25	400	19945
10.	Barseen (R)	12500	100	1800	1070	90	400	9040
11.	Mustard (R)	15000	100	1500	1070	145	400	11785
12.	Fruits & Veg. (R)	11200	200	2000	1070	115	400	7415

(K) – Kharif Crop; (R) – Rabi Crop

5.8 WEIGHTAGE OF VARIOUS PERFORMANCE EVALUATION CRITERIA

A total of seven criteria (indicators) are evaluated for sixteen irrigation subsystems (denoted as IS1 to IS16) of MBSP to assess their performance and to rank them accordingly. This enables in selecting suitable irrigation subsystem that can be made a pilot subsystem to formulate guidelines so that the efficiency and performance of the other irrigation subsystems can be improved. The performance criteria chosen are Land Development Works (LDW), Timely Supply of Inputs (TSI), Conjunctive Use of Water resources (CUW), Participation of Farmers' (PF), Economic Impact (EI), Crop PRoductivity (CPR) and Environmental Conservation (EC). A management expert was requested to act as a decision maker due to his vast experience in the field of Multicriterion Decision Making and allied fields and his acquaintance with the planning problem. The decision maker was requested to assess the relative importance of seven criteria using Analytic Hierarchy Process (AHP). The decision maker was provided with additional information such as responses from questionnaire in the form of summary, villages covered, socio-economic conditions of the farmers' in MBSP. Opinion of the project officials are also explained to him as additional information.

The decision maker was requested to fill in the pairwise comparison matrix based on Saaty's nine-point scale of AHP (Saaty and Gholamnezhad, 1982; Saaty, 1990) and presented in Table 5.6. Maximum eigen value ($\lambda_{\max}$) computed by the AHP methodology is based on the given inputs by the decision maker. The eigen vector corresponding to maximum eigen value ($\lambda_{\max}$) is computed. Normalized eigen vector values are weightages of performance criteria. Maximum eigen value ($\lambda_{\max}$) and consistency index (CI) are found to be 7.7637 and 0.1273 i.e., $\left(\frac{7.7637-7}{7-1}\right)$ as explained in the AHP methodology in Chapter 4. Consistency ratio (C_R) which is ratio of consistency index to random index (its value is 1.32 for matrix size N'=7) is 0.0964. It is found that C_R is less than 0.1 indicating that judgments given by decision maker are satisfactory.

It is observed from Table 5.6 that weights of EI, CPR, CUW, PF, EC, TSI and LDW are 0.3554, 0.1928, 0.1179, 0.1171, 0.0925, 0.0881 and 0.0362 respectively. The two criteria EI and CPR contribute approximately 55% to the importance that affects ranking where as other criteria contribute around 45%.

Table 5.6 Pairwise comparison matrix and resulting weights of criteria by Analytic Hierarchy Process methodology

	LDW	TSI	CUW	PF	EI	CPR	EC	Weights
LDW	1	½	1/3	1/5	1/6	1/4	1/3	0.0362
TSI	2	1	1/3	1/3	1/5	1/2	3	0.0881
CUW	3	3	1	1	1/3	1/2	1	0.1179
PF	5	3	1	1	1/3	1/3	1/2	0.1171
EI	6	5	3	3	1	3	5	0.3554
CPR	4	2	2	3	1/3	1	3	0.1928
EC	3	1/3	1	2	1/5	1/3	1	0.0925

$\lambda_{max} = 7.7637$; $N' = 7$; $CI = 0.1273$; $RI = 1.32$; $C_R = 0.0964$

5.9 FORMULATION OF PAYOFF MATRIX FOR PERFORMANCE EVALUATION SCENARIO

Sixteen irrigation subsystems of the Mahi Bajaj Sagar Project are considered in the present analysis. Payoff matrix is formulated based on the responses from project officials at various levels, interactions with farmers' and interviews with them using structured questionnaire and available project reports. Two matrices, namely, analyst (researcher) and farmer's payoff matrix are formulated.

Formulation of analyst (researcher) payoff matrix is based on his feedback of visiting the irrigation subsystems, interaction with the farmers' and officials of the project and available reports. Each criterion for the respective irrigation subsystem was assessed subjectively based on a numerical scale of 0-100 [Excellent (100), Very Good (80), Good (60), Fair (40), Average (20), Unsatisfactory (0)]. Payoff matrix is presented in Table 5.7.

Flexibility is also provided to choose the intermediate values other than those marked on numerical scale to minimize subjectivity while assessing the criteria values.

It is observed from Table 5.7 that the payoff matrix values are ranging from 20 to 85. The land development works are given a maximum value of 65 in Arthuna (IS5) and Udpura (IS7). Timely supply of inputs is given a maximum value of 85 in Badliya (IS6) and Udpura (IS7). Conjunctive use of water resources was given a high value of 60 in Karan Pur (IS11) and low value of 25 to Gopinath Ka Gara (IS3) and Loharia (IS13). It is also observed that participatory irrigation management is getting prominence as evident from their involvement in repair and rehabilitation work of the canals. Very good participation of farmers' is observed in Narwali (IS9) which is given a high value of 80.

Table 5.7 Payoff matrix formulated by the analyst

IS. No.	Irrigation Subsystem	LDW	TSI	CUW	PF	EI	CPR	EC
IS1	Banka	35	75	40	65	40	45	65
IS2	Chhich	40	**35**	45	55	45	55	60
IS3	Gopinath	**20**	80	**25**	50	60	50	70
IS4	Parsoliya	40	40	55	55	65	60	**80**
IS5	Arthuna	**65**	45	50	45	50	50	65
IS6	Badliya	45	**85**	30	70	50	**70**	55
IS7	Udpura	**65**	**85**	45	35	50	30	**35**
IS8	Bhawarwad	50	75	55	60	**70**	45	70
IS9	Narwali	45	65	50	**80**	55	45	45
IS10	Jagpura	35	60	35	65	55	60	70
IS11	Karan Pur	50	75	**60**	70	40	65	60
IS12	Ganoda	55	80	50	70	65	60	45
IS13	Loharia	50	55	**25**	30	45	40	70
IS14	Badi Saderi	55	65	40	25	**35**	50	75
IS15	Asoda	35	60	45	50	40	60	**35**
IS16	Khodan	25	65	30	60	50	**25**	50
MIN		20	35	25	25	35	25	35
MAX		65	85	60	80	70	70	80
RANGE		45	50	35	55	35	45	45

Economic impact and crop productivity are given a high value of 70 for Bhawarwad (IS8) and Badliya (IS6) respectively and low value to Badi Saderi (35) and Khodan (25) respectively. High environmental conservation (80) is given for Parsoliya and less in Udpura (35).

Payoff matrix for each farmer is formulated based on the above mentioned numerical scale and their views about the irrigation subsystem to which they belong. The average of the total farmers' response for each irrigation subsystem for each criterion is presented in Table 5.8. Averaging of payoff matrix values given by farmers' and analyst is made to consider both views in a holistic manner. Average payoff matrix presented in Table 5.9 is used for grouping and ranking of irrigation subsystems.

Table 5.8 Average payoff matrix of farmers'

S. No.	Irrigation Subsystem	LDW	TSI	CUW	PF	EI	CPR	EC
IS1	Banka	37	74	38	67	45	44	63
IS2	Chhich	33	69	46	52	39	51	57
IS3	Gopinath	24	84	26	44	54	57	68
IS4	Parsoliya	42	42	57	56	63	54	74
IS5	Arthuna	63	52	44	49	49	51	65
IS6	Badliya	46	84	36	67	47	64	54
IS7	Udpura	69	83	43	41	52	34	36
IS8	Bhawarwad	55	78	48	55	57	52	66
IS9	Narwali	44	64	44	76	53	46	47
IS10	Jagpura	39	57	36	64	61	58	68
IS11	Karan Pur	47	83	51	52	37	62	62
IS12	Ganoda	53	77	47	69	59	59	49
IS13	Loharia	47	56	29	35	50	43	72
IS14	Badi Saderi	51	66	39	29	46	49	69
IS15	Asoda	33	58	46	47	53	58	39
IS16	Khodan	29	61	32	54	51	29	46
MIN		24	42	26	29	37	29	36
MAX		69	84	57	76	63	64	74
RANGE		45	42	31	47	26	35	38

It is observed from the Table 5.8 that the payoff matrix values range from 24 to 84. It is noticed that timely supply of inputs is very good in Gopinath Ka Gara (IS3) and Badliya (IS6) whereas there is less utilization of conjunctive use of water. Conjunctive use of water resources is less evident in Gopinath Ka Gara (IS3) with a value of 26 and more in Parsoliya (IS4) with a value of 57. There is a correlation of less supply of inputs and less utilization of conjunctive use of water. Less use of conjunctive use of water may be attributed to the less requirements or more pumping cost. It is also observed that land development works are given low value of 24 for Gopinath Ka Gara (IS3) whereas these are given high value of 69 for Udpura (IS7) by group of farmers'.

Table 5.9 Average payoff matrix

S. No.	Irrigation Subsystem	LDW	TSI	CUW	PF	EI	CPR	EC
IS1	Banka	36	75	39	66	43	45	64
IS2	Chhich	37	52	46	54	42	53	59
IS3	Gopinath Ka Gara	22	82	26	47	57	54	69
IS4	Parsoliya	41	41	56	56	64	57	77
IS5	Arthuna	64	49	47	47	50	51	65
IS6	Badliya	46	85	33	69	49	67	55
IS7	Udpura	67	84	44	38	51	32	36
IS8	Bhawarwad	53	77	52	58	64	49	68
IS9	Narwali	45	65	47	78	54	46	46
IS10	Jagpura	37	59	36	65	58	59	69
IS11	Karan Pur	49	79	56	61	39	64	61
IS12	Ganoda	54	79	49	70	62	60	47
IS13	Loharia	49	56	27	33	48	42	71
IS14	Badi Saderi	53	66	46	27	41	50	72
IS15	Asoda	34	59	46	49	47	59	37
IS16	Khodan	27	63	31	57	51	27	48
MIN		22	41	26	27	39	27	36
MAX		67	85	56	78	64	67	77
RANGE		45	44	30	51	25	40	41

Similarly, more participation of farmers' is observed with a value of 76 in Narwali (IS9) and less in Badi Saderi (IS14). It is also observed that economic impact is more in Parsoliya (IS4) with a value of 63 and less in Karan Pur (IS11) with a value of 37. A similar trend is observed for crop productivity in Badliya (IS6) with 64 which is rated very high in supply of inputs with a value of 84. Environmental conservation with a value of 74 is given for Parsoliya (IS4) and less in Udpura (IS7) with a value of 36. Payoff matrix values presented in Tables 5.7 and 5.8 represents the subjective opinion of the analyst and a group of farmers' based on a sample survey of 208.

The objective of the present study is to understand the system characteristics to make the study more meaningful and develop a systematic and scientific methodology. The data used in modeling is obtained from various sources such as project reports, secondary sources such as discussions with project officials, experts, farmers' and response survey analysis. The developed methodology can be further improved whenever updated and precise information is available.

The data pertaining to various parameters are used to obtain the results of Part 1 and Part 2 of the studies undertaken. The next chapter presents the results and discussion of both the studies, namely, reservoir operation for irrigation planning (Part 1) and performance evaluation of irrigation subsystems (Part 2).

CHAPTER 6

RESULTS AND DISCUSSION

6.1 INTRODUCTION

This chapter presents the results of the studies in two parts. Part 1 is related to the irrigation planning aspects. It includes results of the planning model obtained by Real-coded Genetic Algorithms (RGA), Differential Evolution (DE), Simulated Annealing (SA), Simulated Quenching (SQ) and Linear Programming (LP). Comparative analysis of results are made with respect to the annual net benefits, cropping pattern, reservoir storage, release and ground water pumping policies. Extensive sensitivity analysis is performed on various parameters that are employed in RGA, DE, SA and SQ to assess their effect on annual net benefits and ascertain the appropriate parameters. Finally, the cropping pattern, monthly storage and release policies etc., that can be implemented for the case study are discussed.

Part 2 of chapter 6 is related to performance evaluation studies of the sixteen irrigation subsystems. Seven performance criteria, namely, land development works, timely supply of inputs, conjunctive use of water resources, participation of farmers', economic impact, crop productivity and environmental conservation are analyzed. Results of Kohonen Artificial Neural Networks (KANN) methodology employed for classification of irrigation subsystems are discussed in detail. Three Multicriterion Decision Making (MCDM) techniques, namely, Multicriterion Q-Analysis-2, Multi Attribute Utility Theory and Compromise Programming are employed to rank the grouped irrigation subsystems (after classification). Spearman Rank Correlation technique is used to analyze the correlation between the ranks obtained by the three MCDM techniques. Extensive sensitivity analysis is performed for KANN and MCDM techniques. Guidelines that are proposed for the improvement of irrigation subsystems are also discussed.

PART 1: OPTIMAL RESERVOIR OPERATION FOR IRRIGATION PLANNING

6.2 ANALYSIS OF RESULTS (PART 1)

Seventy five percent dependable inflow level (Patra, 2002) is considered for the planning problem as explained in Section 5.3. Dependable inflow values into the reservoir for the month of June, July, August, September and October are 14.73, 73.26, 669.13, 1066.69 and 1057.12 Mm^3 respectively. Inflows into the reservoir for other months are not significant and are neglected. The originally proposed Culturable Command Area (CCA) of Mahi Bajaj Sagar Project (MBSP) is 80,000 ha (Phase 1) and the revised (proposed) CCA in Phase 2 is 1,23,500 ha. Out of these, already 57,531 ha has been opened for irrigation. Present study is analyzed in 2 scenarios.

In **Scenario 1**, model is validated for CCA that is opened for irrigation and proposed as per phase 1. Accordingly the lower and upper limits are fixed based on cropping intensity of 89% i.e., 89% of 57,531 ha and 89% of 80,000 ha with existing live storage of reservoir 1829.27 Mm^3. Similarly in **Scenario 2**, model is validated for CCA that is opened for irrigation and proposed as per phase 2. Lower and upper limits are fixed based on cropping intensity of 89% i.e., 89% of 57, 531 ha and 89% of 1,23,500 ha and increase of live storage to 2000 Mm^3 (i.e., decrease of dead storage from 351.13 Mm^3 to 180.39 Mm^3) (MBSP Report on Revised Project Estimate of Unit-II, 2001). These aspects were discussed in detail with project officials before formulating the above two scenarios.

Results of the analysis carried out for two scenarios are presented separately in sections 6.3 and 6.4. Sensitivity analysis on parameters is also included in these sections. The total number of variables and constraints (excluding bounds) in the irrigation planning model are 160 and 93 respectively. The following subsections explain the implementation aspects of optimization techniques.

6.2.1 Implementation Aspects of Optimization Techniques

Developed model is solved using RGA, DE, SA, SQ and results obtained are compared with those of LP. Interactive computer programs in C environment are developed for RGA, DE, SA and SQ. Provision for estimating the CPU time requirement is also made using inbuilt functions in C for further analysis. LINDO (Linear, INteractive and Discrete Optimizer) software (http://www.lindo.com) is used for solving LP. Penalty function approach is used in RGA, DE, SA and SQ techniques to convert the constrained problem into unconstrained problem. High penalty function parameter value of 10^{19} is employed for all four non-traditional optimization techniques (Deb, 1995; Deb, 2000; Rao, 2003). Due to this, the solution falling outside the restricted solution region is penalized with a high penalty. The penalty forces the solution to adjust itself in such a way that after a few generations/iterations it may fall into the restricted solution space.

In the present study, second order penalty term is used (Deb, 1995). Objective function of unconstrained optimization problem consists of penalty term that includes the constraints of the constrained optimization problem which is nonlinear and objective function of constrained problem (Rao, 2003). In this regard, objective function of the unconstrained optimization problem is always nonlinear irrespective of whether the objective function of the constrained optimization problem is linear or nonlinear (Raju and Nagesh Kumar, 2004). The objective function of the unconstrained optimization problem in irrigation planning context is the summation of linear objective function as per Eq. 4.1 and penalty term that includes the constraints as per Eqs. 4.2 to 4.21. Moreover, RGA, DE, SA and SQ which are capable of solving nonlinear problems effectively are employed in the present study to assess their applicability in irrigation planning and simultaneously exploring their potentiality to solve high dimensional problems which are existing in the present study (160 variables and 93 constraints). Implementation details for various techniques are given below:

6.2.1.1 Real-coded Genetic Algorithms (RGA)

Real coding with SBX crossover operator and parameter-based mutation is implemented. Tournament selection has been used in the study as it has better chances of convergence that requires lesser computational time (Goldberg and Deb, 1991; Deb, 1999). The parameters considered are population size POP=1100 (normally 5 to 10 times the number of the variables used in the model), crossover probability XR=0.80 (normally in the range of 0.5 to 1.0) and mutation probability MUT=0.01 (normally in the range of 0 to 0.10) (Deb, 1995; Deb, 1999; Deb, 2000). The number of generations is fixed as 3000 (after numerous iterations) whereas the distribution index for SBX and mutation is fixed as 2 and 100 respectively as suggested by Deb (2000). The above chosen parameters are given as input to the developed model. However, various combination of parameters were tested which are explained in sensitivity analysis section. Section C-1 of Appendix C presents the pseudo code and flow chart of the computer program that is developed for this purpose.

6.2.1.2 Differential Evolution (DE)

Differential Evolution (DE) strategy DE/rand/1/bin as initially proposed by Price and Storn (2005) is used. The parameters considered are population size NP=1100 (which is 5 to 10 times the number of variables used in the model), crossover constant CR=1.0 (normally in the range of 0.5 to 1.0), weighting factor F=0.5 (normally in the range of 0.5 to 1.0) (Onwubolu and Babu, 2004; Price and Storn, 2005). The number of generations and accuracy between two successive generations is fixed as 3000 and 10^{-7} respectively.

Comparison of results are also made among the ten DE strategies (DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/randtobest/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/randtobest/1/exp) for NP=1100, CR=1.0, F=0.5. These strategies are denoted as DE1 to DE10. The above chosen parameters are given as input to the developed model. However, various combination of parameters were tested which are explained in sensitivity analysis section. Section C-2 of Appendix C presents the pseudo code and flow chart of the computer program that is developed for this purpose.

6.2.1.3 Simulated Annealing (SA)

The parameters used for the study are number of iterations NI=130 (normally in the range of 50 to 150), initial temperature T=900 (problem specific and fixed after trial and error), and cooling rate CoR=0.80 (normally in the range of 0.70 to 0.95) (Ingber, 1993; Deb, 1995; Rao, 2003). The final temperature and the accuracy to be achieved between the successive iterations are fixed as 0.1 and 10^{-5}. The above chosen parameters are given as input to the developed model. However, various combination of parameters were tested which are explained in sensitivity analysis section. Section C-3 of Appendix C presents the pseudo code and flow chart of the computer program that is developed for this purpose.

6.2.1.4 Simulated Quenching (SQ)

The parameters used for the study are number of iterations NI''=140 (normally in the range of 50 to 150), initial temperature T''=800 (problem specific and fixed after trial and error) and cooling rate CoR''=0.80 (usually in the range of 0.70 to 0.95) (Ingber, 1993; Deb, 1995; Rao, 2003). The final temperature and the accuracy to be achieved between the successive iterations are fixed as 0.1 and 10^{-5}. The above chosen parameters are given as input to the developed model. However, various combination of parameters were tested which are explained in sensitivity analysis section. Section C-3 of Appendix C presents the pseudo code and flow chart of the computer program that is developed for this purpose.

6.2.1.5 Linear Programming (LP)

LINDO software (http://www.lindo.com) that can solve LP based irrigation planning model is used. No specific parameter is employed in this optimization technique (as compared to four non-traditional optimization techniques).

6.3 SCENARIO 1

6.3.1 Comparison of Results Obtained by Five Solution Techniques (Scenario 1)

Table 6.1 presents the cropping pattern for Left Main Canal (LMC), Right Main Canal (RMC) and Bhungra Canal (BC), annual net benefits obtained for the chosen set of parameters of each technique as explained in Sections 6.2.1.1 to 6.2.1.5. It also includes the lower and upper limits for each variable for comparative purpose. The terms annual net benefits and net benefits are used interchangeably in the present study. Table 6.2 presents the storage policy obtained by five techniques. Table 6.3 presents the release policy for hydropower generation in *PH 1*. Tables 6.4, 6.5, 6.6 presents the release policy for irrigation for LMC, RMC and BC whereas Table 6.7 presents the ground water pumping policy obtained by the five techniques. The following observations are made from the analysis of the results:

1. **Cropping Pattern (LMC)**
   (a) It is observed from Table 6.1 that cropping area of Maize (K) has reached its lower limit for LP methodology whereas upper limit in case of SQ. The cropping area obtained by LP has reached the upper limit in case of Paddy (K).
   (b) Similar trend is observed for Cotton (K) where the crop areas obtained by all techniques oriented towards the upper limit.
   (c) In case of Sugarcane (K), all four techniques except SA yields similar values (in the range of 624 ha to 637 ha). In case of Zaid Crop (K), LP, DE and SA are oriented towards upper limit whereas RGA and SQ oriented towards lower limit.
   (d) The percentage deviation of area of crops that are grown in Kharif season as compared to upper limit are 4.61 i.e., $\left(\frac{(101.42-96.74)\times 100}{101.42}\right)$, 5.84, 4.68, 7.98 and 5.85 for LP, RGA, DE, SA and SQ respectively. It is observed that the lowest deviation is of 4.61 % (in case of LP) and highest is of 7.98 % (in case of SA).
   (e) The percentage deviation of total area of crops (for Rabi season) as compared to upper limit is 2.20, 2.58, 2.63, 8.90 and 17.36 for LP, RGA, DE, SA and SQ respectively.
   (f) It is observed from total area of crops grown (for both Kharif and Rabi seasons) that LP, RGA, DE yields similar values with a difference of 200 ha (35068 ha

for LP and 34847 ha for RGA). There is significant difference of total areas (1981 ha) obtained by SA and SQ.

(g) The ratio of total area to lower limit (in percentage) is 126.32 i.e., $\left(\frac{350.68 \times 100}{277.61}\right)$, 125.53, 125.90, 118.83 and 111.69 for LP, RGA, DE, SA and SQ respectively.

2. **Cropping Pattern (RMC)**

(a) Low crop area is observed for SQ solution methodology in case of Cotton (K). It is also observed that the difference between crop area obtained by SA and SQ is 708 ha. Similarly, the difference between SA and SQ is 486 ha for Pulses (K).

(b) The percentage deviation of total area of crops (for both Kharif and Rabi seasons) as compared to upper limit is 3.75, 4.66, 3.80, 21.35 and 13.66 for LP, RGA, DE, SA and SQ respectively.

(c) The ratio of total area to lower limit (in percentage) is 137.60, 136.29, 137.53, 112.43 and 123.42 for LP, RGA, DE, SA and SQ respectively.

3. **Cropping Pattern (BC)**

(a) The total area of crops (for both Kharif and Rabi seasons) that are obtained by LP, RGA, DE, SA and SQ are 1878 ha, 1838 ha, 1861 ha, 2108 ha and 2077 ha. It is observed that LP, RGA and DE yield similar values whereas SA and SQ yields similar values.

(b) The ratio of total area to lower limit (in percentage) is 176.01, 172.26, 174.41, 197.56 and 194.66 for LP, RGA, DE, SA and SQ respectively.

4. **Cropping Pattern (Total area of LMC+RMC+BC)**

(a) Total area in Kharif is 18672 ha, 18431 ha, 18645 ha, 17972 ha and 17997 ha respectively for LP, RGA, DE, SA and SQ whereas it is 49064 ha, 48752 ha, 48940 ha, 42282 ha, 42705 ha respectively in case of Rabi.

(b) Percentage deviation of total area (both Rabi and Kharif) from its upper limit is 4.87, 5.65, 5.08, 15.38 and 14.75 for LP, RGA, DE, SA and SQ.

(c) The ratio of total area (both Rabi and Kharif) to lower limit (in percentage) is 132.28, 131.20, 131.99, 117.67 and 118.55 for LP, RGA, DE, SA and SQ respectively.

(d) It is observed from above result pattern that LP, RGA and DE can be considered as one group whereas SA and SQ can be considered as other group. This also supports the theory that RGA and DE are population based search techniques whereas SA and SQ are point by point search techniques.

5. **Reservoir Operation**

(a) It is observed from Table 6.2 that empty storage is observed in the month of August and maximum live storage in the month of November. Storage values obtained by RGA, DE, SA and SQ are different from LP during February to July.

(b) It is observed that overflows of around 424 Mm^3 occurred in the month of October for all the five techniques. Effective utilization of overflows is necessary which otherwise goes unutilized. This aspect is discussed in Scenario 2.

(c) Table 6.3 presents release policy for hydropower generation for *PH 1* obtained by five solution techniques. It is observed that even though the monthly releases obtained by various techniques are different, the annual releases are almost similar.

(d) Table 6.4 presents annual surface water releases for LMC as obtained by five solution techniques. These are similar in case of LP, RGA and DE (around 303 Mm^3) and 288.67 Mm^3, 276.37 Mm^3 in case of SA and SQ respectively (releases obtained by SA are more than SQ).

(e) Table 6.5 presents annual surface water releases for RMC as obtained by five solution techniques. These are similar in case of LP, RGA and DE (around 265 Mm^3) and 227.29 Mm^3, 238.98 Mm^3 in case of SA and SQ respectively (releases obtained by SQ are more than SA).

(f) Table 6.6 presents annual surface water releases for Bhungra canal as obtained by five solution techniques. These are similar in case of LP, RGA and DE (around 15 Mm^3) and 18.89 Mm^3, 19.32 Mm^3 in case of SA and SQ respectively.

(g) It is observed from Tables 6.4, 6.5, 6.6 that monthly irrigation releases to LMC, RMC and BC are far less than the corresponding canal capacities.

6. **Ground Water**

(a) It is observed from Table 6.7 that the utilization of ground water is maximum (31.07 Mm^3) in LP solution methodology whereas it is less (19.89 Mm^3) in case of SA solution methodology.

(b) Considerable ground water withdrawal of 24.74 Mm^3, 18.90 Mm^3, 18.99 Mm^3, 19.89 Mm^3 and 21.31 Mm^3 is observed in the month of July for LP, RGA, DE, SA and SQ respectively.

7. **Net Benefits**

It is observed from Table 6.1 that net benefits are Rs.113.15 crores, Rs.111.65 crores, Rs.112.68 crores, Rs.100.27 crores and Rs.99.77 crores for LP, RGA, DE, SA and SQ respectively. This is on par with the conclusion regarding the groups as discussed above.

The above results are based on the parameters as chosen by the analyst with various inputs from literature, researchers working in this field and his experience in dealing with similar problems. It is observed that careful selection of parameters is very important to come to a conclusion. This aspect is handled by extensive sensitivity analysis as discussed in Section 6.3.3. Section 6.3.2 presents comparison of results obtained by ten DE strategies.

Table 6.1 Cropping pattern obtained by the five techniques

Crops	Crop area in '00 ha						
	Lower Limit	Upper Limit	LP	RGA	DE	SA	SQ
Maize (LMC) – K	9.36	12.17	9.36	10.43	9.53	10.21	12.17
Paddy (LMC) – K	12.48	16.23	16.23	15.88	16.15	15.71	15.76
Cotton (LMC) – K	28.07	36.51	36.51	36.22	36.49	34.44	34.19
Pulses (LMC) – K	15.60	20.29	20.29	19.77	20.18	17.29	20.20
Sugarcane (LMC) – K	6.24	8.11	6.24	6.30	6.26	7.61	6.37
Zaid Crop (LMC) – K	6.24	8.11	8.11	6.90	8.06	8.07	6.80
Area in Kharif (LMC)	77.99	101.42	96.74	95.50	96.67	93.33	95.49
Wheat (LMC) – R	93.57	121.71	121.71	120.38	121.66	103.51	102.11
Barley (LMC) – R	13.10	17.04	13.10	15.77	13.24	13.23	14.64
Gram (LMC) – R	78.60	102.24	102.24	100.55	100.64	102.07	82.41
Barseen (LMC) – R	5.93	7.71	5.93	6.52	6.46	7.60	6.37
Mustard (LMC) – R	6.86	8.93	8.93	8.10	8.91	8.21	7.20
Fruits & Veg. (LMC) – R	1.56	2.03	2.03	1.65	1.92	1.93	1.85
Area in Rabi (LMC)	199.62	259.66	253.94	252.97	252.83	236.55	214.58
Total Area (Kharif+Rabi) (LMC)	277.61	361.08	350.68	348.47	349.50	329.88	310.07
Maize (RMC) – K	7.54	10.78	7.54	9.11	7.60	9.41	10.48
Paddy (RMC) – K	10.06	14.38	14.38	13.72	14.35	11.89	10.82
Cotton (RMC) – K	22.63	32.35	32.35	32.08	32.34	32.15	25.07
Pulses (RMC) – K	12.57	17.97	17.97	16.89	17.95	13.11	17.97
Sugarcane (RMC) – K	5.03	7.19	5.03	5.29	5.03	6.89	6.75
Zaid Crop (RMC) – K	5.03	7.19	7.19	6.20	7.14	6.85	7.17
Area in Kharif (RMC)	62.86	89.86	84.46	83.29	84.41	80.30	78.26
Wheat (RMC) – R	75.42	107.82	107.82	107.40	107.75	77.34	80.99
Barley (RMC) – R	10.56	15.09	10.56	11.62	10.70	12.06	13.06
Gram (RMC) – R	63.36	90.57	90.57	88.97	89.36	66.43	89.95

Crops	Crop area in '00 ha						
	Lower Limit	Upper Limit	LP	RGA	DE	SA	SQ
Barseen (RMC) – R	4.78	6.83	4.78	5.97	5.95	6.25	5.11
Mustard (RMC) – R	5.53	7.91	7.91	6.25	7.82	7.89	7.37
Fruits & Veg. (RMC) – R	1.26	1.80	1.80	1.48	1.75	1.31	1.44
Area in Rabi (RMC)	160.91	230.02	223.44	221.69	223.33	171.28	197.92
Total Area (Kharif+Rabi) (RMC)	223.77	319.88	307.90	304.98	307.74	251.58	276.18
Maize (BC) – K	0.36	1.05	0.36	0.48	0.36	0.51	0.41
Paddy (BC) – K	0.48	1.40	0.48	0.56	0.51	0.77	1.19
Cotton (BC) – K	1.08	3.14	3.14	2.92	3.10	3.14	2.89
Pulses (BC) – K	0.60	1.75	0.60	0.66	0.60	0.62	0.64
Sugarcane (BC) – K	0.24	0.70	0.24	0.25	0.24	0.38	0.66
Zaid Crop (BC) – K	0.24	0.70	0.70	0.65	0.56	0.67	0.43
Area in Kharif (BC)	3.00	8.74	5.52	5.52	5.37	6.09	6.22
Wheat (BC) – R	3.60	10.47	3.60	4.21	3.69	10.14	7.70
Barley (BC) – R	0.50	1.47	0.50	0.65	0.53	0.51	1.24
Gram (BC) – R	3.02	8.79	8.10	6.90	7.80	3.11	4.64
Barseen (BC) – R	0.23	0.66	0.23	0.60	0.43	0.50	0.30
Mustard (BC) – R	0.26	0.77	0.77	0.40	0.71	0.67	0.52
Fruits & Veg. (BC) – R	0.06	0.17	0.06	0.10	0.08	0.06	0.15
Area in Rabi (BC)	7.67	22.33	13.26	12.86	13.24	14.99	14.55
Total Area (Kharif+Rabi) (BC)	10.67	31.07	18.78	18.38	18.61	21.08	20.77
Total Area (Kharif) (LMC+RMC+BC)	143.85	200.02	186.72	184.31	186.45	179.72	179.97
Total Area (Rabi) (LMC+RMC+BC)	368.20	512.01	490.64	487.52	489.40	422.82	427.05
Total Area (Kharif+Rabi) (LMC+RMC+BC)	512.05	712.03	677.36	671.83	675.85	602.54	607.02
Net Benefits (Rupees in Crores)			113.15	111.65	112.68	100.27	99.77

K-Kharif, R-Rabi, LMC-Left Main Canal, RMC-Right Main Canal, BC-Bhungra Canal

Table 6.2 Storage policy obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	1186.08	1186.10	1186.08	1185.22	1185.43
February	885.61	891.42	891.37	889.97	890.24
March	660.48	666.31	666.23	664.36	664.68
April	489.59	495.39	495.34	493.01	493.39
May	330.88	336.68	336.63	334.28	334.62
June	174.41	180.20	180.16	177.75	177.99
July	48.69	54.46	54.44	51.89	51.95
August	0.00	0.00	0.00	0.00	0.00
September	514.60	514.62	514.60	516.78	515.69
October	1416.61 (423.40)*	1416.61 (423.44)*	1416.60 (423.40)*	1418.61 (425.28)*	1417.41 (423.99)*
November	1829.27	1829.27	1829.27	1829.27	1829.27
December	1508.41	1508.44	1508.42	1508.22	1508.28

*The value in braces denotes the overflows in Mm^3

Table 6.3 Release policy for hydropower generation in *PH 1* obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	182.57	176.81	176.81	176.81	176.81
February	189.82	189.82	189.82	189.82	189.82
March	143.36	143.36	143.36	143.36	143.36
April	126.37	126.37	126.37	126.37	126.37
May	116.81	116.81	116.81	116.81	116.81
June	109.38	109.38	109.38	109.38	109.38
July	98.76	104.47	104.50	101.76	101.65
August	133.82	133.77	133.82	131.44	132.41
September	141.77	141.77	141.77	141.77	141.77
October	195.13	195.13	195.13	195.13	195.13
November	203.09	203.09	203.09	203.09	203.09
December	206.41	206.41	206.41	206.41	206.41
Total	1847.29	1847.18	1847.27	1842.14	1842.99

Table 6.4 Release policy for irrigation for Left Main Canal obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	56.14	56.15	55.93	52.50	47.76
February	59.11	59.10	58.88	55.35	50.18
March	16.37	16.36	16.34	15.08	14.16
April	0.90	0.90	0.90	1.09	0.92
May	2.40	2.42	2.41	2.93	2.45
June	12.58	12.60	12.59	12.70	12.74
July	22.67	22.63	22.67	22.00	22.96
August	28.16	28.16	28.16	27.12	28.36
September	26.74	26.76	26.74	25.80	26.73
October	18.75	18.71	18.75	18.42	18.24
November	14.73	14.64	14.70	13.81	13.00
December	45.11	45.08	44.98	41.87	38.87
Total	303.66	303.51	303.05	288.67	276.37

Table 6.5 Release policy for irrigation for Right Main Canal obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	49.28	49.27	49.28	38.14	43.89
February	51.92	51.89	51.92	40.04	46.30
March	14.31	14.31	14.31	11.45	12.44
April	0.73	0.76	0.73	0.97	0.96
May	1.94	2.03	1.94	2.65	2.60
June	10.84	10.89	10.84	10.78	10.51
July	19.69	19.60	19.69	18.51	18.85
August	24.52	24.47	24.53	23.19	22.92
September	23.31	23.32	23.31	22.39	21.26
October	16.38	16.39	16.38	16.44	13.99
November	12.95	12.91	12.94	11.15	10.97
December	39.63	39.62	39.63	31.59	34.31
Total	265.50	265.45	265.50	227.29	238.98

Table 6.6 Release policy for irrigation for Bhungra Canal obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	2.82	2.80	2.82	3.36	3.30
February	3.01	2.98	3.01	3.49	3.44
March	0.67	0.70	0.67	1.13	1.06
April	0.03	0.04	0.04	0.05	0.09
May	0.09	0.10	0.09	0.15	0.25
June	0.57	0.60	0.58	0.72	0.90
July	1.05	1.10	1.05	1.24	1.41
August	1.46	1.49	1.46	1.66	1.79
September	1.51	1.52	1.51	1.69	1.79
October	1.25	1.22	1.25	1.38	1.47
November	0.86	0.84	0.86	1.06	1.00
December	2.30	2.29	2.30	2.96	2.81
Total	15.63	15.68	15.64	18.89	19.32

Table 6.7 Ground water pumping policy obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	3.99	9.74	9.53	0.00	0.00
February	2.34	2.30	2.11	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00
July	24.74	18.90	18.99	19.89	21.31
August	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00
Total	31.07	30.95	30.63	19.89	21.31

6.3.2 Comparison of Results Obtained by Ten DE Strategies (Scenario 1)

Comparative analysis of results are made for ten DE strategies, namely, DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/randtobest/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/randtobest/1/exp. These are denoted as DE1 to DE10 respectively. These strategies were analyzed for NP=1100, CR=1.0, F=0.5 as implemented for DE1 strategy (Section 6.3.1). Table 6.8 presents the cropping pattern for LMC, RMC and BC, annual net benefits obtained for the chosen set of parameters for all ten DE strategies. It includes the lower and upper limits for each variable. Table 6.9 presents the storage policy obtained by all ten DE strategies. Table 6.10 presents the release policy for hydropower generation in *PH 1*. Tables 6.11, 6.12, 6.13 present the release policy for irrigation for LMC, RMC and BC whereas Table 6.14 presents ground water pumping policy obtained by ten DE strategies. The following observations are made from the analysis of the results:

1. **Cropping Pattern (LMC)**

   (a) It is observed from Table 6.8 that the lowest crop area (9463 ha) is obtained by DE6 strategy whereas the highest crop area (9674 ha) is obtained by DE4 strategy in Kharif season with a difference in area of 211 ha. It is also observed that all the ten DE strategies are oriented towards the upper limit. The difference of area between upper limit (10142 ha) and DE4 strategy (highest crop area) is found to be 468 ha.

   (b) The percentage deviation of total area (both Kharif and Rabi) for DE1 to DE10 is 3.21, 3.16, 3.26, 2.89, 3.41, 3.66, 3.44, 3.18, 2.99 and 2.95 respectively from the upper limit. It is observed that the minimum and maximum deviations are 2.89 % (DE4) and 3.66 % (DE6) respectively.

2. **Cropping Pattern (RMC)**

   The percentage deviations from upper limit for total area (both Kharif and Rabi) are 3.80, 4.34, 4.11, 3.78 (minimum), 4.00, 4.28, 4.59, 4.13, 4.00 and 4.65 (maximum) for DE1 to DE10 respectively. Minimum and maximum deviations from upper limit occurred for DE4 and DE10 strategies.

3. **Cropping Pattern (BC)**

The deviation of total area (both Kharif and Rabi) are more from upper limit (around 1300 ha) as compared to lower limit (around 700 to 800 ha) for all ten DE strategies.

4. **Cropping Pattern (Total area of LMC+RMC+BC)**

Considering the total area scenario (both Kharif and Rabi), the percentage deviation from the upper limit is 5.08, 5.30, 5.25, 4.93, 5.35, 5.67, 5.67, 5.30, 5.07 and 5.38 for DE1 to DE10 respectively. Minimum and maximum deviations from upper limit are observed for DE4 and DE7 strategies.

5. **Reservoir Operation**

(a) It is observed from Table 6.9 that the storage values obtained by ten DE strategies are almost similar. It is observed that empty storage is observed in the month of August and maximum storage in the month of November for all ten DE strategies.

(b) It is observed that overflows of around 424 Mm^3 occurred in the month of October for all the ten DE strategies.

(c) No variation is observed for water releases for hydropower generation in *PH 1* for January to June, September, November and December for ten DE strategies. The variation is insignificant for July, August and October as observed in Table 6.10.

(d) Annual irrigation releases for LMC is maximum (303.92 Mm^3) for DE7 strategy and minimum (301.29 Mm^3) for DE6 strategy with a variation of 2.63 Mm^3 (Table 6.11).

(e) In case of RMC, annual irrigation releases are maximum (265.50 Mm^3) for DE1 strategy and minimum (263.67 Mm^3) for DE7 strategy with a variation of 1.83 Mm^3 (Table 6.12).

(f) In case of Bhungra Canal, annual irrigation releases are maximum (15.83 Mm^3) for DE2 strategy and minimum (15.46 Mm^3) for DE6 strategy with a variation of 0.37 Mm^3 (Table 6.13).

6. **Ground Water**

It is observed from Table 6.14 that the ground water utilization is in three months (January, February and July) only.

7. **Net Benefits**

It is observed from Table 6.8 that the net benefits are varying from Rs.110.86 crores (DE7 strategy) to Rs.112.71 crores (DE4 strategy) with a range of Rs.1.85 crores.

Sensitivity analysis aspects of various parameters that were employed in RGA, DE, SA and SQ are discussed in detail in the next section.

Table 6.8 Cropping pattern obtained by ten DE strategies

Crops	Crop Area ('00 ha)										
	Lower Limit	Upper Limit	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
Maize (LMC) – K	9.36	12.17	9.53	11.29	9.78	9.38	10.89	10.01	10.81	9.68	9.67	9.86
Paddy (LMC) – K	12.48	16.23	16.15	15.21	16.15	16.22	15.57	14.58	15.48	16.13	16.09	16.05
Cotton (LMC) – K	28.07	36.51	36.49	36.04	36.39	36.51	36.37	36.51	36.20	36.42	36.49	36.47
Pulses (LMC) – K	15.60	20.29	20.18	19.25	19.99	20.28	19.41	18.70	19.52	20.08	20.11	20.00
Sugarcane (LMC) – K	6.24	8.11	6.26	6.27	6.26	6.24	6.34	6.76	6.61	6.28	6.24	6.24
Zaid Crop (LMC) – K	6.24	8.11	8.06	7.90	7.60	8.11	7.47	8.07	6.93	8.02	8.08	7.96
Total Area (LMC)- K	77.99	101.42	96.67	95.96	96.17	96.74	96.05	94.63	95.55	96.61	96.68	96.58
Wheat (LMC) – R	93.57	121.71	121.66	121.24	121.41	121.70	121.55	116.60	121.11	119.94	121.67	121.48
Barley (LMC) – R	13.10	17.04	13.24	14.06	15.07	13.17	14.53	16.93	16.49	15.82	13.39	13.50
Gram (LMC) – R	78.60	102.24	100.64	100.41	100.03	100.73	100.53	101.82	97.39	101.62	101.09	101.55
Barseen (LMC) – R	5.93	7.71	6.46	7.35	7.15	7.38	6.63	7.49	7.33	5.95	6.93	6.47
Mustard (LMC) – R	6.86	8.93	8.91	8.76	7.52	8.90	7.58	8.77	8.92	7.88	8.52	8.82
Fruits & Veg. (LMC) – R	1.56	2.03	1.92	1.90	1.97	2.01	1.88	1.63	1.87	1.78	2.00	2.02
Total Area (LMC) - R	199.62	259.66	252.83	253.72	253.15	253.89	252.70	253.24	253.11	252.99	253.60	253.84
Total Area (LMC)	277.61	361.08	349.50	349.68	349.32	350.63	348.75	347.87	348.66	349.60	350.28	350.42
Maize (RMC) – K	7.54	10.78	7.60	7.93	9.49	7.59	9.50	9.49	8.73	10.57	7.83	7.66
Paddy (RMC) – K	10.06	14.38	14.35	14.12	13.49	14.35	13.69	13.77	13.65	13.38	14.26	14.35
Cotton (RMC) – K	22.63	32.35	32.34	32.32	32.25	32.34	32.22	31.79	31.96	32.04	32.30	32.29
Pulses (RMC) – K	12.57	17.97	17.95	17.97	16.88	17.94	16.69	16.94	17.47	16.05	17.80	17.92
Sugarcane (RMC) – K	5.03	7.19	5.03	5.05	5.08	5.03	5.07	5.06	5.35	5.03	5.04	5.06
Zaid Crop (RMC) – K	5.03	7.19	7.14	6.55	6.87	7.18	6.85	7.12	7.04	7.15	7.08	6.84
Total Area (RMC) - K	62.86	89.86	84.41	83.94	84.06	84.43	84.02	84.17	84.20	84.22	84.31	84.12
Wheat (RMC) – R	75.42	107.82	107.75	107.31	107.14	107.80	106.26	106.41	100.83	106.19	107.54	105.62
Barley (RMC) – R	10.56	15.09	10.70	11.34	10.88	10.63	13.46	13.02	14.82	13.88	11.28	11.25
Gram (RMC) – R	63.36	90.57	89.36	89.50	90.09	89.07	88.09	89.02	89.73	89.12	88.33	88.88
Barseen (RMC) – R	4.78	6.83	5.95	6.05	5.42	6.24	5.90	6.11	6.30	4.95	6.80	6.08
Mustard (RMC) – R	5.53	7.91	7.82	6.20	7.65	7.83	7.85	5.84	7.59	6.73	7.12	7.38

Crops	Crop Area ('00 ha)											
	Lower Limit	Upper Limit	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
Fruits & Veg. (RMC) – R	1.26	1.80	1.75	1.67	1.50	1.78	1.50	1.63	1.74	1.58	1.71	1.69
Total Area (RMC) - R	160.91	230.02	223.33	222.07	222.68	223.35	223.06	222.03	221.01	222.45	222.78	220.90
Total Area (RMC)	223.77	319.88	307.74	306.01	306.74	307.78	307.08	306.20	305.21	306.67	307.09	305.02
Maize (BC) – K	0.36	1.05	0.36	0.37	0.51	0.36	0.44	0.39	0.37	0.44	0.37	0.37
Paddy (BC) – K	0.48	1.40	0.51	0.68	0.49	0.49	0.56	0.72	0.87	0.48	0.49	0.51
Cotton (BC) – K	1.08	3.14	3.10	2.92	2.90	3.13	2.87	2.37	2.52	3.00	3.10	3.10
Pulses (BC) – K	0.60	1.75	0.60	0.68	0.65	0.60	0.62	1.00	0.72	0.66	0.62	0.61
Sugarcane (BC) – K	0.24	0.70	0.24	0.26	0.24	0.24	0.25	0.25	0.26	0.24	0.24	0.26
Zaid Crop (BC) – K	0.24	0.70	0.56	0.67	0.42	0.65	0.31	0.24	0.24	0.27	0.56	0.42
Total Area (BC) - K	3.00	8.74	5.37	5.58	5.21	5.47	5.05	4.97	4.98	5.09	5.38	5.27
Wheat (BC) – R	3.60	10.47	3.69	3.89	3.81	3.64	4.54	5.81	5.86	3.70	3.74	3.81
Barley (BC) – R	0.50	1.47	0.53	0.87	0.91	0.65	0.86	1.25	0.58	0.98	0.55	0.70
Gram (BC) – R	3.02	8.79	7.80	7.26	7.51	7.72	6.37	4.55	5.46	7.47	7.63	7.50
Barseen (BC) – R	0.23	0.66	0.43	0.44	0.30	0.51	0.47	0.46	0.41	0.36	0.51	0.49
Mustard (BC) – R	0.26	0.77	0.71	0.48	0.72	0.43	0.71	0.44	0.40	0.35	0.67	0.43
Fruits & Veg. (BC) – R	0.06	0.17	0.08	0.10	0.10	0.07	0.09	0.12	0.06	0.08	0.11	0.07
Total Area (BC) - R	7.67	22.33	13.24	13.04	13.35	13.02	13.04	12.63	12.77	12.94	13.21	13.00
Total Area (BC)	10.67	31.07	18.61	18.62	18.56	18.49	18.09	17.60	17.75	18.03	18.59	18.27
Total Area – K (LMC+RMC+BC)	143.85	200.02	186.45	185.48	185.44	186.64	185.12	183.77	184.73	185.92	186.37	185.97
Total Area – R (LMC+RMC+BC)	368.20	512.01	489.40	488.83	489.18	490.26	488.80	487.90	486.89	488.38	489.59	487.74
Total Area (LMC+RMC+BC)	512.05	712.03	675.85	674.31	674.62	676.90	673.92	671.67	671.62	674.30	675.96	673.71
Net Benefits (Crores of Rupees)			112.68	112.06	112.15	112.71	111.72	111.17	110.86	111.81	112.48	112.26

K-Kharif, R-Rabi, LMC-Left Main Canal, RMC-Right Main Canal, BC-Bhungra Canal

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,

DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.9 Storage policy obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	1186.08	1186.10	1186.10	1186.07	1186.09	1186.14	1186.08	1186.10	1186.07	1186.06
February	891.37	891.38	891.36	891.37	891.40	891.47	891.38	891.39	891.37	891.35
March	666.23	666.25	666.19	666.23	666.31	666.42	666.27	666.26	666.23	666.22
April	495.34	495.33	495.27	495.34	495.36	495.39	495.26	495.36	495.33	495.31
May	336.63	336.62	336.56	336.63	336.64	336.68	336.55	336.65	336.62	336.60
June	180.16	180.14	180.09	180.16	180.17	180.21	180.07	180.18	180.15	180.12
July	54.44	54.37	54.37	54.45	54.45	54.45	54.29	54.46	54.43	54.40
August	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	514.60	514.66	514.62	514.61	514.63	515.32	514.60	514.60	514.61	514.59
October	1416.60 (423.40)*	1416.64 (423.45)*	1416.64 (423.49)*	1416.61 (423.40)*	1416.66 (423.52)*	1417.39 (424.37)*	1416.65 (423.54)*	1416.61 (423.43)*	1416.61 (423.41)*	1416.59 (423.39)*
November	1829.27	1829.27	1829.27	1829.27	1829.27	1829.27	1829.27	1829.27	1829.27	1829.27
December	1508.42	1508.44	1508.44	1508.42	1508.44	1508.49	1508.46	1508.44	1508.42	1508.42

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,
DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

*The value in braces denotes the overflows in Mm^3

Table 6.10 Release policy for hydropower generation in *PH 1* obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	176.81	176.81	176.81	176.81	176.81	176.81	176.81	176.81	176.81	176.81
February	189.82	189.82	189.82	189.82	189.82	189.82	189.82	189.82	189.82	189.82
March	143.36	143.36	143.36	143.36	143.36	143.36	143.36	143.36	143.36	143.36
April	126.37	126.37	126.37	126.37	126.37	126.37	126.37	126.37	126.37	126.37
May	116.81	116.81	116.81	116.81	116.81	116.81	116.81	116.81	116.81	116.81
June	109.38	109.38	109.38	109.38	109.38	109.38	109.38	109.38	109.38	109.38
July	104.50	104.37	104.42	104.51	104.51	104.44	104.29	104.53	104.50	104.46
August	133.82	133.72	133.80	133.82	133.82	133.10	133.82	133.82	133.82	133.83
September	141.77	141.77	141.77	141.77	141.77	141.77	141.77	141.77	141.77	141.77
October	195.13	195.13	195.13	195.13	195.13	195.13	195.13	195.13	195.13	195.13
November	203.09	203.09	203.09	203.09	203.09	203.09	203.09	203.09	203.09	203.09
December	206.41	206.41	206.41	206.41	206.41	206.41	206.41	206.41	206.41	206.41
Total	1847.27	1847.03	1847.17	1847.27	1847.27	1846.48	1847.06	1847.29	1847.25	1847.23

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,
DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.11 Release policy for irrigation for Left Main Canal obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	55.93	56.15	56.22	56.14	56.14	56.16	56.12	56.15	56.14	56.14
February	58.88	59.11	59.18	59.11	59.09	59.11	59.01	59.11	59.11	59.11
March	16.34	16.37	16.40	16.37	16.39	16.29	16.52	16.34	16.36	16.37
April	0.90	0.90	0.90	0.90	0.91	0.96	0.95	0.90	0.90	0.90
May	2.41	2.41	2.41	2.40	2.44	2.60	2.54	2.42	2.40	2.40
June	12.59	12.51	12.59	12.58	12.60	12.33	12.65	12.60	12.58	12.59
July	22.67	22.52	22.65	22.67	22.62	21.99	22.64	22.67	22.66	22.66
August	28.16	28.03	28.15	28.16	28.16	27.45	28.17	28.16	28.16	28.17
September	26.74	26.63	26.74	26.74	26.78	26.19	26.77	26.74	26.74	26.75
October	18.75	18.57	18.74	18.75	18.74	18.57	18.73	18.75	18.74	18.75
November	14.70	14.65	14.70	14.73	14.70	14.65	14.68	14.66	14.72	14.71
December	44.98	45.06	45.18	45.11	45.13	44.99	45.13	45.09	45.11	45.10
Total	303.03	302.92	303.85	303.65	303.70	301.29	303.92	303.60	303.63	303.66

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,
DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.12 Release policy for irrigation for Right Main Canal obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	49.28	49.27	49.21	49.28	49.29	49.34	48.84	49.31	49.28	48.81
February	51.92	51.91	51.84	51.92	51.89	51.97	51.44	51.92	51.91	51.43
March	14.31	14.26	14.26	14.31	14.32	14.27	14.06	14.31	14.30	14.13
April	0.73	0.73	0.73	0.73	0.73	0.73	0.77	0.73	0.73	0.73
May	1.94	1.94	1.95	1.94	1.95	1.95	2.06	1.94	1.94	1.95
June	10.84	10.83	10.83	10.84	10.86	10.87	10.89	10.86	10.84	10.85
July	19.69	19.69	19.62	19.69	19.63	19.68	19.69	19.63	19.68	19.68
August	24.53	24.56	24.52	24.52	24.52	24.52	24.52	24.52	24.52	24.53
September	23.31	23.35	23.36	23.31	23.36	23.30	23.30	23.37	23.31	23.31
October	16.38	16.36	16.37	16.38	16.40	16.28	16.31	16.38	16.38	16.38
November	12.94	12.92	12.91	12.95	12.88	12.83	12.71	12.85	12.93	12.84
December	39.63	39.63	39.55	39.63	39.61	39.59	39.09	39.61	39.63	39.26
Total	265.50	265.45	265.14	265.49	265.45	265.33	263.67	265.42	265.44	263.90

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,

DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.13 Release policy for irrigation for Bhungra Canal obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	2.82	2.82	2.85	2.82	2.80	2.78	2.82	2.82	2.82	2.82
February	3.01	3.01	3.04	3.01	2.97	2.92	2.98	3.00	3.01	3.01
March	0.67	0.70	0.70	0.67	0.73	0.81	0.79	0.68	0.68	0.68
April	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04
May	0.09	0.10	0.09	0.09	0.09	0.10	0.10	0.09	0.09	0.10
June	0.58	0.62	0.58	0.57	0.58	0.61	0.63	0.57	0.57	0.58
July	1.05	1.12	1.06	1.05	1.05	1.13	1.11	1.05	1.05	1.05
August	1.46	1.51	1.46	1.46	1.44	1.47	1.46	1.46	1.46	1.46
September	1.51	1.53	1.49	1.51	1.48	1.44	1.46	1.51	1.51	1.52
October	1.25	1.24	1.19	1.25	1.19	1.07	1.15	1.22	1.24	1.25
November	0.86	0.84	0.84	0.86	0.84	0.79	0.82	0.84	0.86	0.86
December	2.30	2.30	2.31	2.30	2.31	2.31	2.34	2.30	2.30	2.31
Total	15.64	15.83	15.65	15.63	15.52	15.46	15.70	15.58	15.64	15.68

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin, DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.14 Ground water pumping policy obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	9.53	9.75	9.75	9.74	9.76	9.82	9.28	9.79	9.74	9.28
February	2.11	2.34	2.33	2.34	2.30	2.40	1.77	2.34	2.34	1.85
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	18.99	18.98	18.98	18.99	18.88	18.37	19.17	18.91	18.98	19.02
August	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	30.63	31.07	31.07	31.07	30.93	30.58	30.22	31.04	31.06	30.15

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin, DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

6.3.3 Sensitivity Analysis

Number of parameters as mentioned in Section 6.2.1 are required in each technique to determine the maximum net benefits and corresponding storage and release policies. Careful selection of these parameters is of utmost importance. In this regard, effect of varying the parameter values on the convergence to the optimal solution is investigated by carrying out sensitivity analysis studies.

6.3.3.1 Real-coded Genetic Algorithms (RGA)

The same settings such as real coding with SBX crossover operator, parameter-based mutation and tournament selection which were employed in the original problem are used. The other parameters used for the study are population size (POP) varied from 1000 to 2000 with an increment of 100 (11 levels), crossover probability (XR) from 0.6 to 1.0 with an increment 0.05 (9 levels) and mutation probability (MUT) with 6 values 0, 0.01, 0.03, 0.05, 0.07, 0.10 (Deb, 1995; Deb, 1999; Deb, 2000). The total number of resulting combinations is $11 \times 9 \times 6 = 594$.

The program is run for 594 combinations to determine the optimal set of parameters and are determined based on two aspects i.e., maximum net benefits and less CPU time requirement. In any given situation, if maximum values of net benefits are same for any given combination(s), the next criteria that is chosen for selecting optimal combination is less CPU time requirement. In this problem, these two aspects were considered for choosing optimal set of parameters. After the extensive sensitivity analysis on the parameters, the optimal set is found as POP=1100, XR=0.90 and MUT=0 which yield net benefits of Rs.113.15 crores taking the CPU time requirement of 108 seconds which is based on PC with Pentium IV 2.4GHz/256MB RAM/40GB HDD. Effect of variation of each parameter is shown in the form of graphs from Fig. 6.1 to 6.21.

The graphs are classified into four types and they are:

- Type I - Fig. 6.1 to Fig 6.6 - Presents the variation of net benefits for different crossover probability XR (0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.00) and population size POP (1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) for various mutation probability MUT (0, 0.01, 0.03, 0.05, 0.07, 0.10).

- Type II - Fig. 6.7 to Fig 6.15 - Presents the variation of net benefits for different mutation probability MUT (0, 0.01, 0.03, 0.05, 0.07, 0.10) and population size POP (1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) for various crossover probability XR (0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.0). This effort is made to understand how the different MUT values in conjunction with XR values affect the net benefits for various population sizes.
- Type III - Fig. 6.16 to Fig. 6.18 - Presents the CPU time variation for different population size POP (1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) and crossover probability XR (0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.0) for various mutation probability MUT values (0.01, 0.05, 0.10). Other variations related to mutation values such as 0, 0.03 and 0.07 are not presented due to their similar trend.
- Type IV - Fig. 6.19 to Fig. 6.21 - Presents the CPU time variation for different population size POP (1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) and mutation probability MUT (0.0, 0.01, 0.03, 0.05, 0.07, 0.10) for various crossover probability (0.60, 0.80, 1.0). Other variations related to crossover probability values such as 0.65, 0.70, 0.75, 0.85, 0.90 and 0.95 are not presented due to their similar trend.

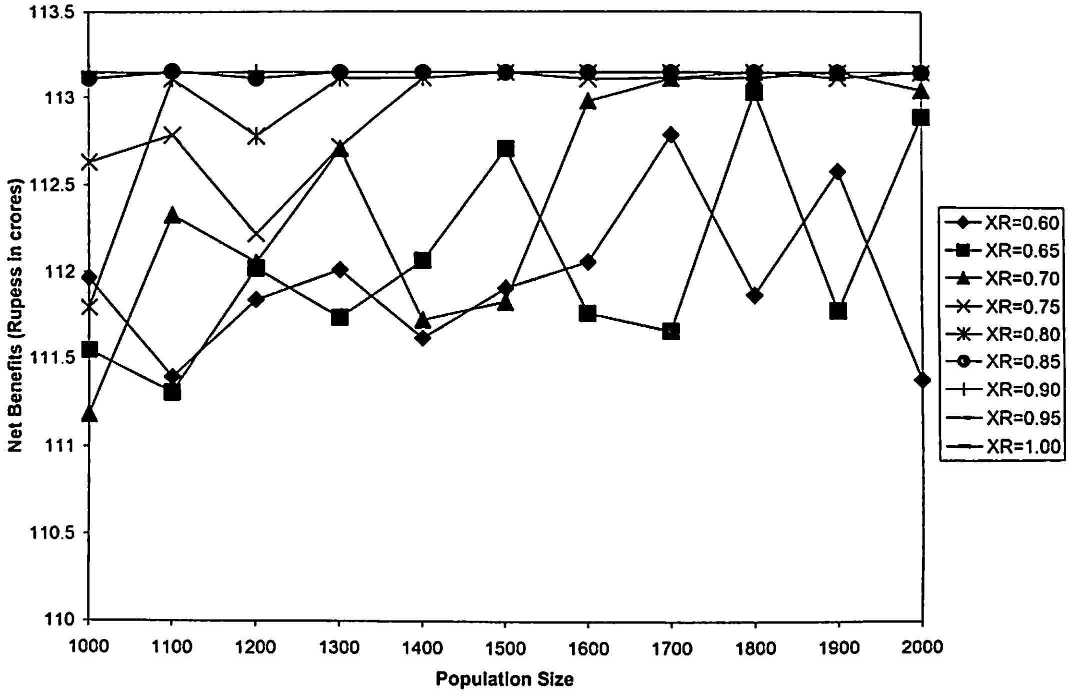

Fig. 6.1 Variation of net benefits for different crossover probabilities and population sizes (MUT=0)

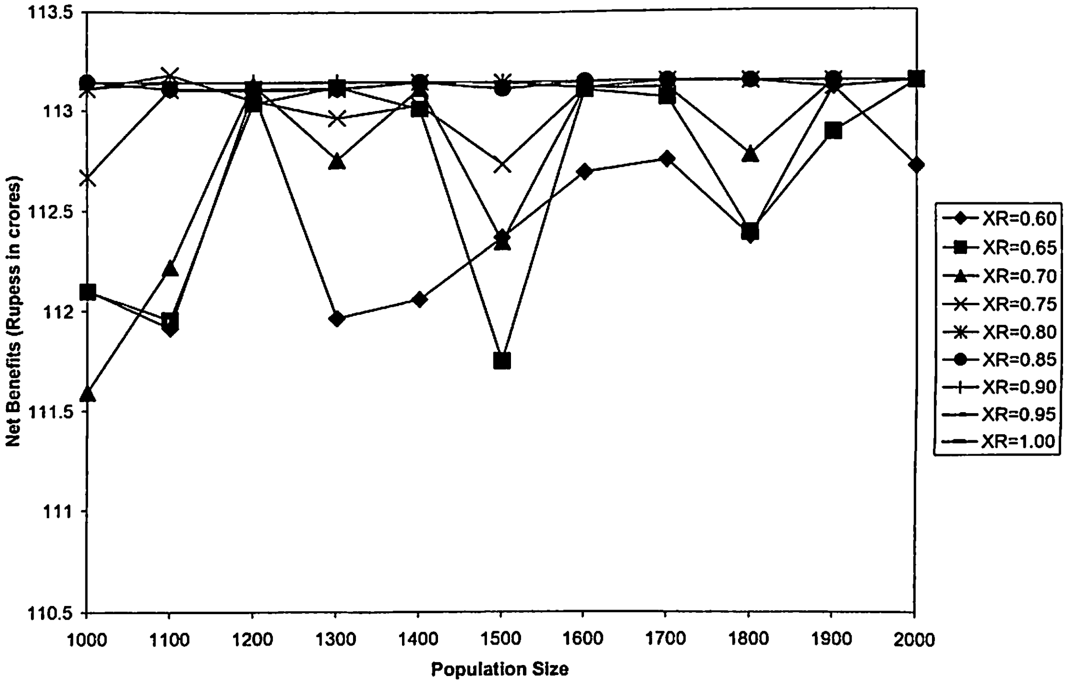

Fig. 6.2 Variation of net benefits for different crossover probabilities and population sizes (MUT=0.01)

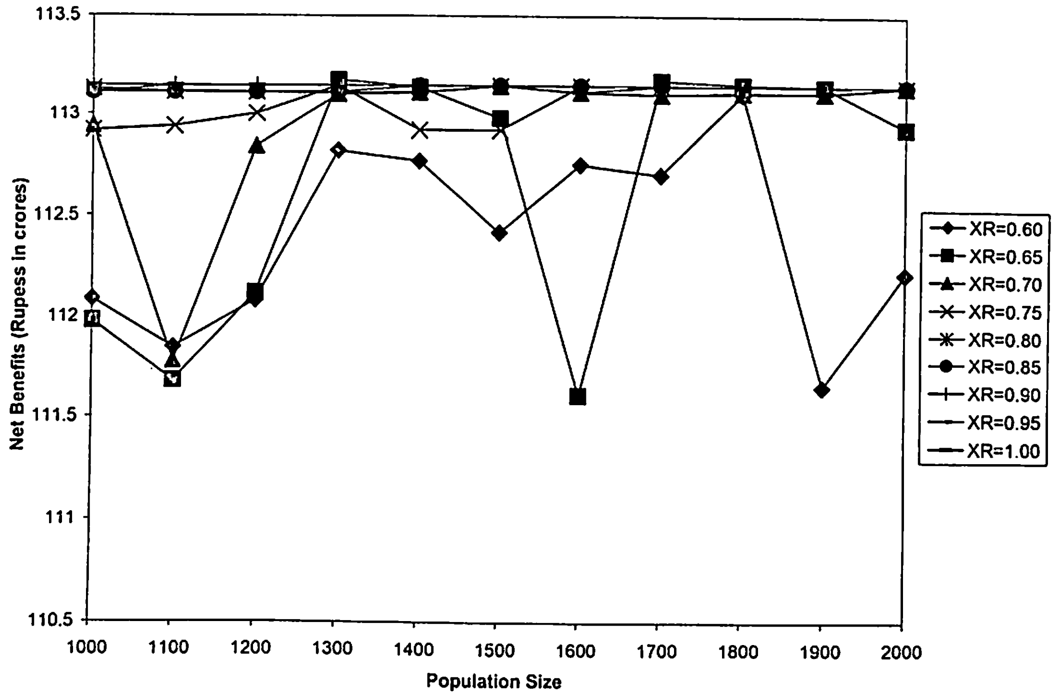

Fig. 6.3 Variation of net benefits for different crossover probabilities and population sizes (MUT=0.03)

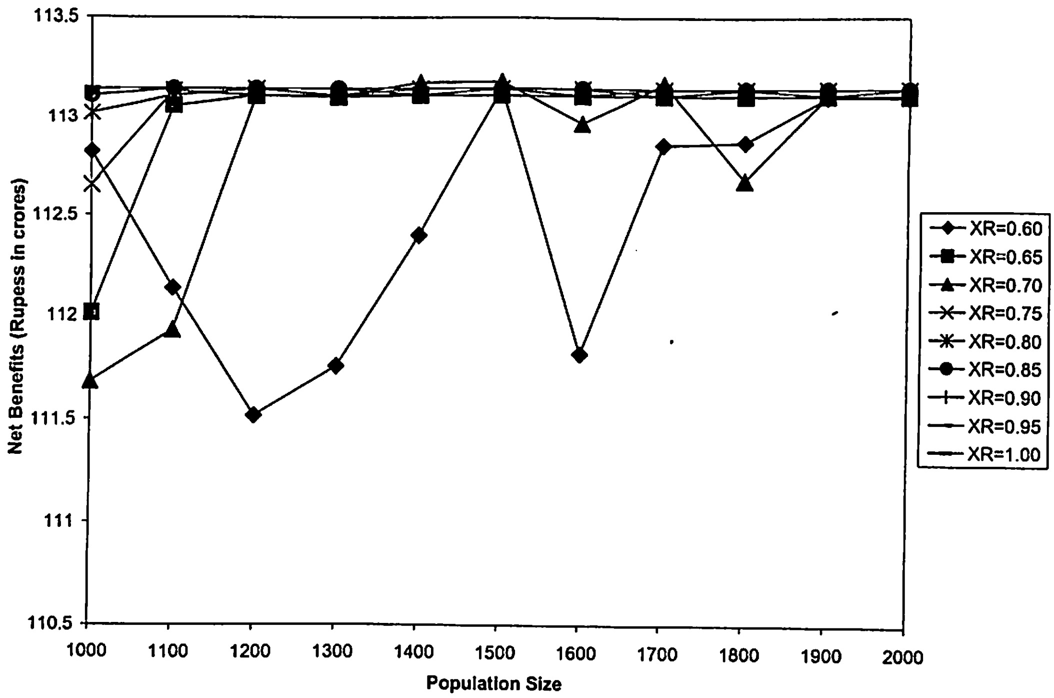

Fig. 6.4 Variation of net benefits for different crossover probabilities and population sizes (MUT=0.05)

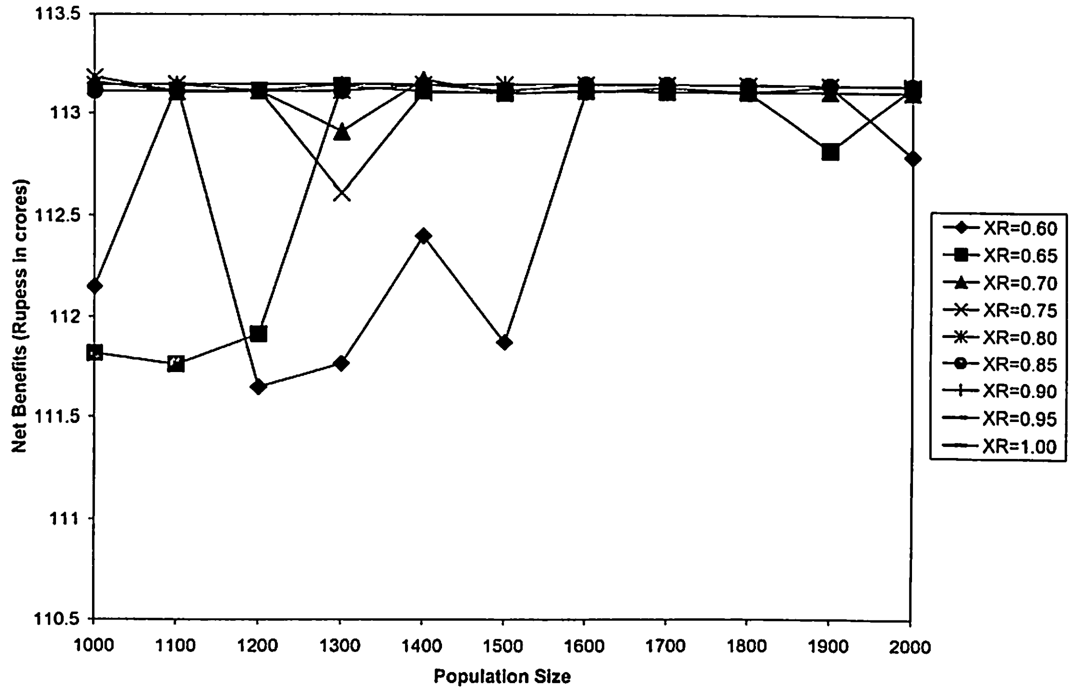

Fig. 6.5 Variation of net benefits for different crossover probabilities and population sizes (MUT=0.07)

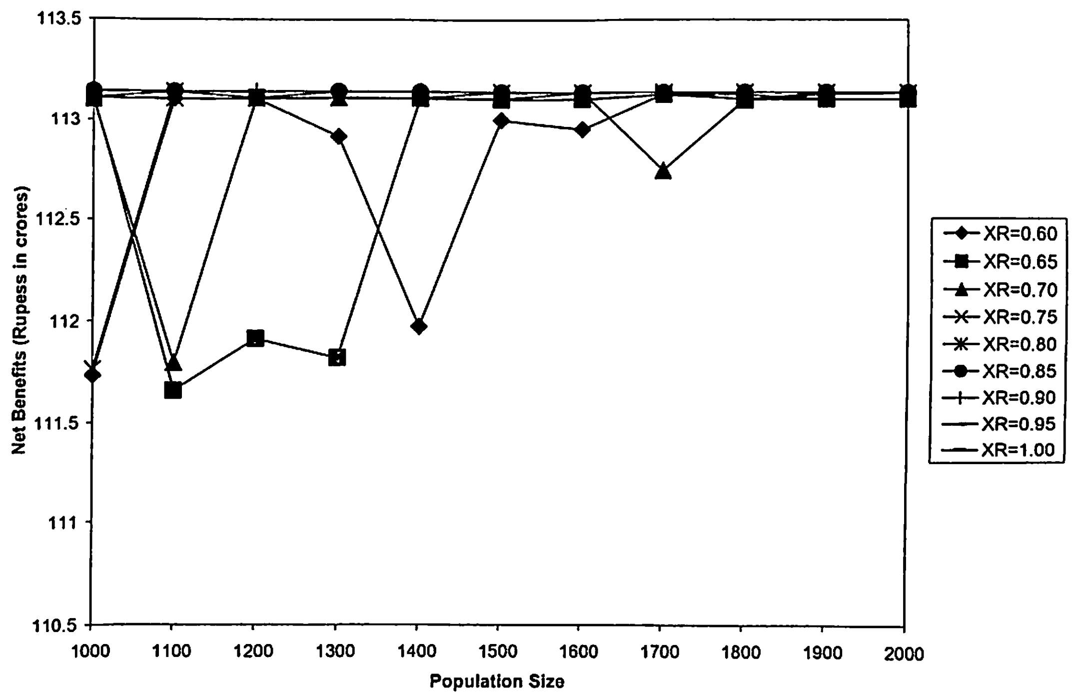

Fig. 6.6 Variation of net benefits for different crossover probabilities and population sizes (MUT=0.10)

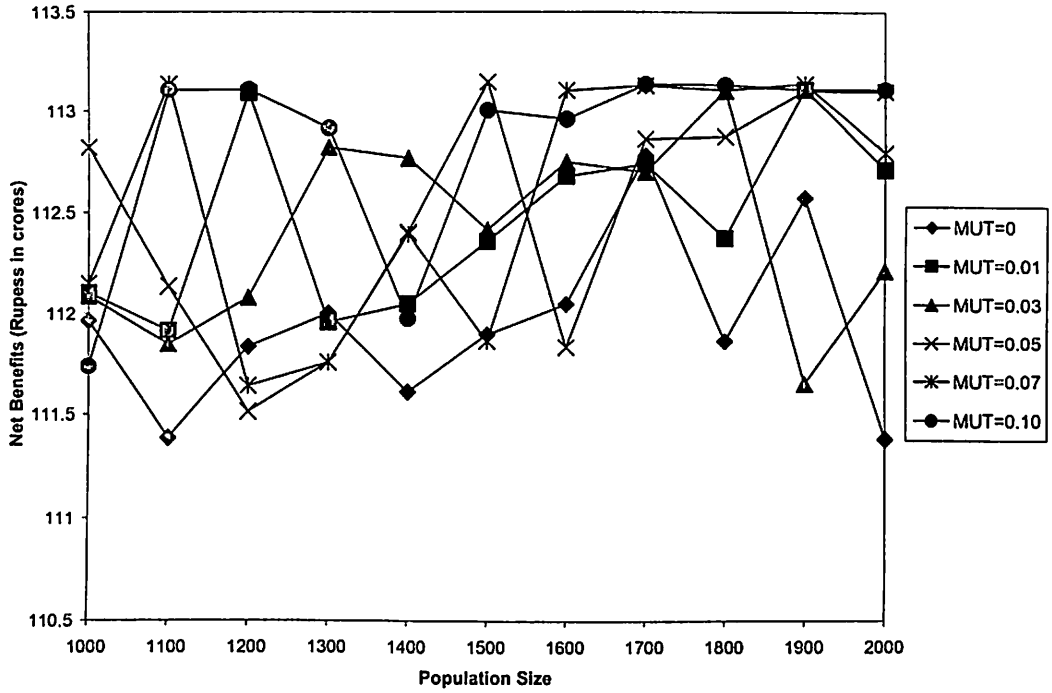

Fig. 6.7 Variation of net benefits for different mutation probabilities and population sizes (XR=0.60)

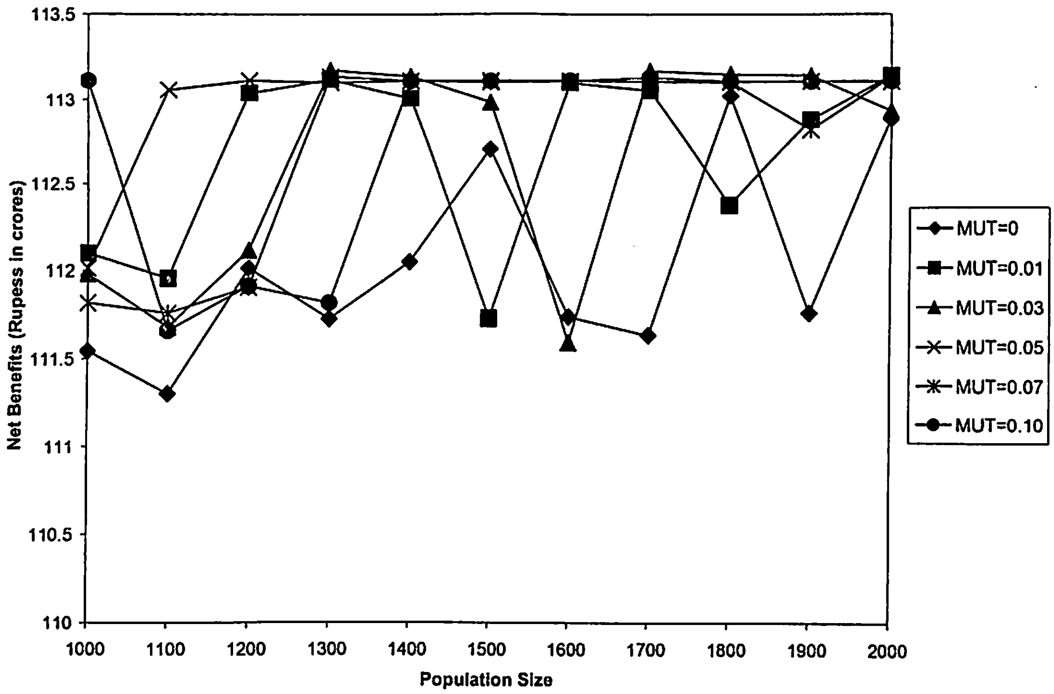

Fig. 6.8 Variation of net benefits for different mutation probabilities and population sizes (XR=0.65)

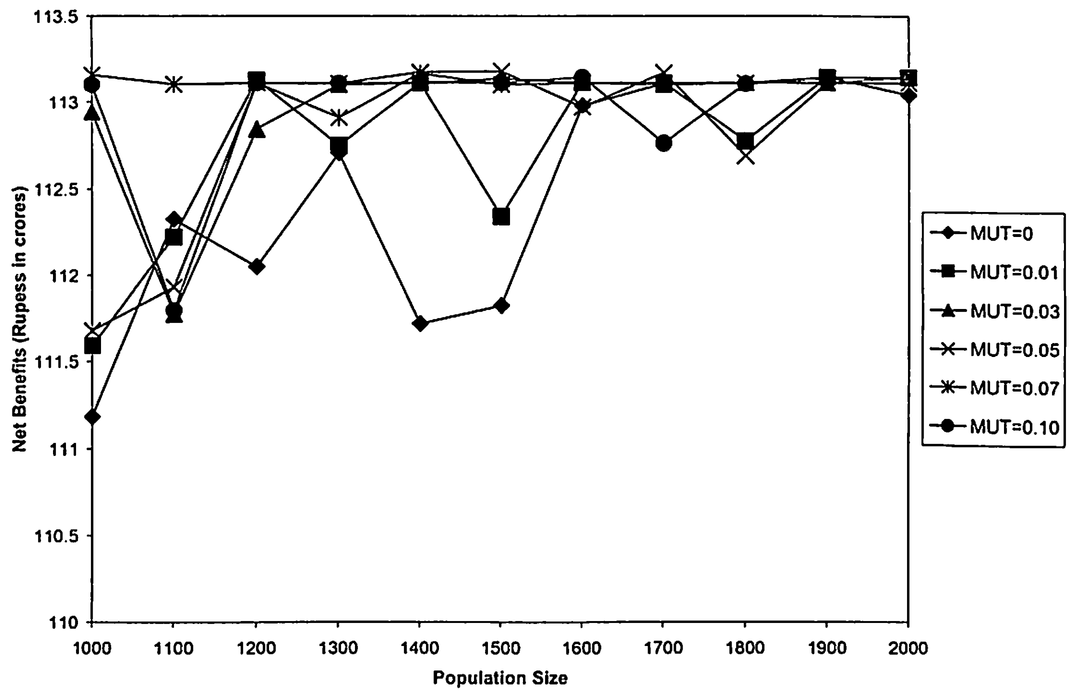

Fig. 6.9 Variation of net benefits for different mutation probabilities and population sizes (XR=0.70)

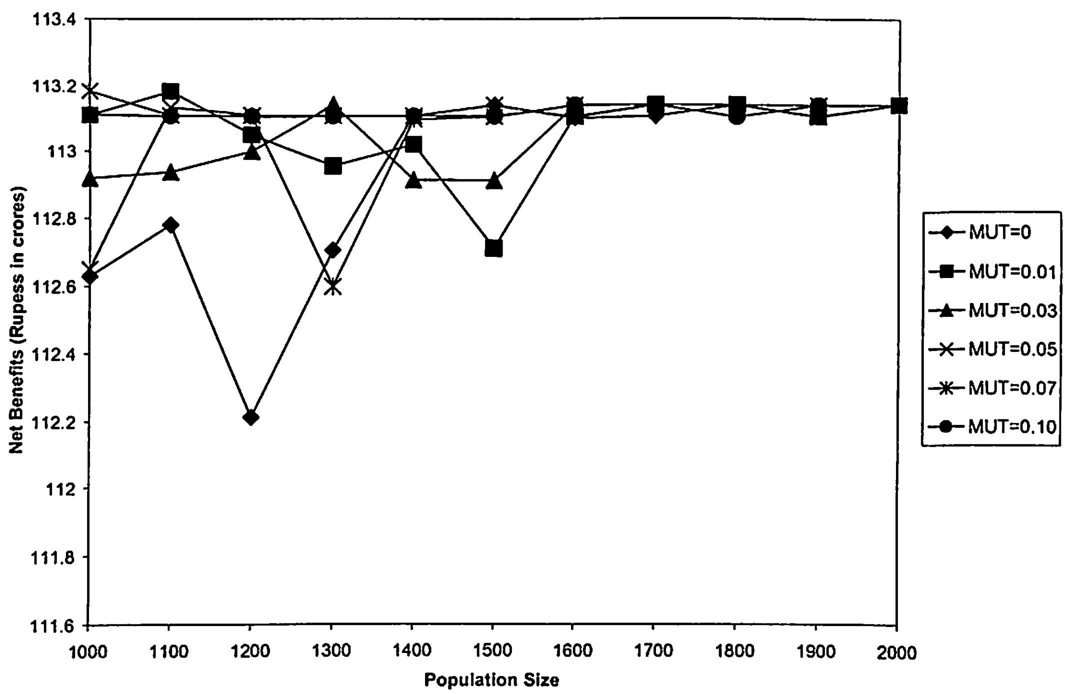

Fig. 6.10 Variation of net benefits for different mutation probabilities and population sizes (XR=0.75)

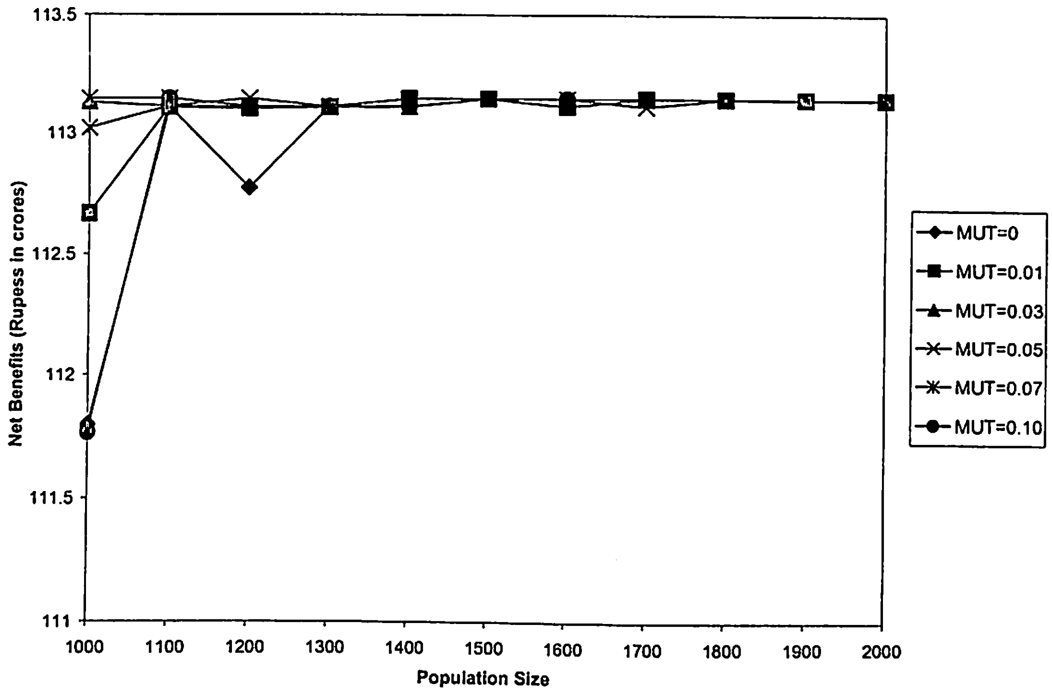

Fig. 6.11 Variation of net benefits for different mutation probabilities and population sizes (XR=0.80)

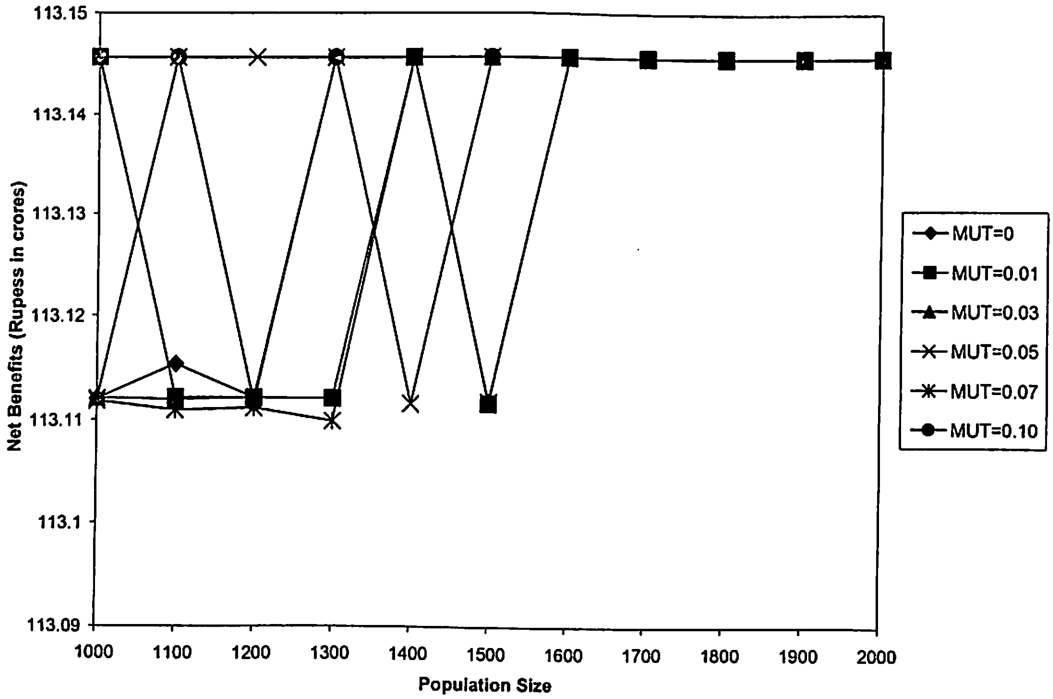

Fig. 6.12 Variation of net benefits for different mutation probabilities and population sizes (XR=0.85)

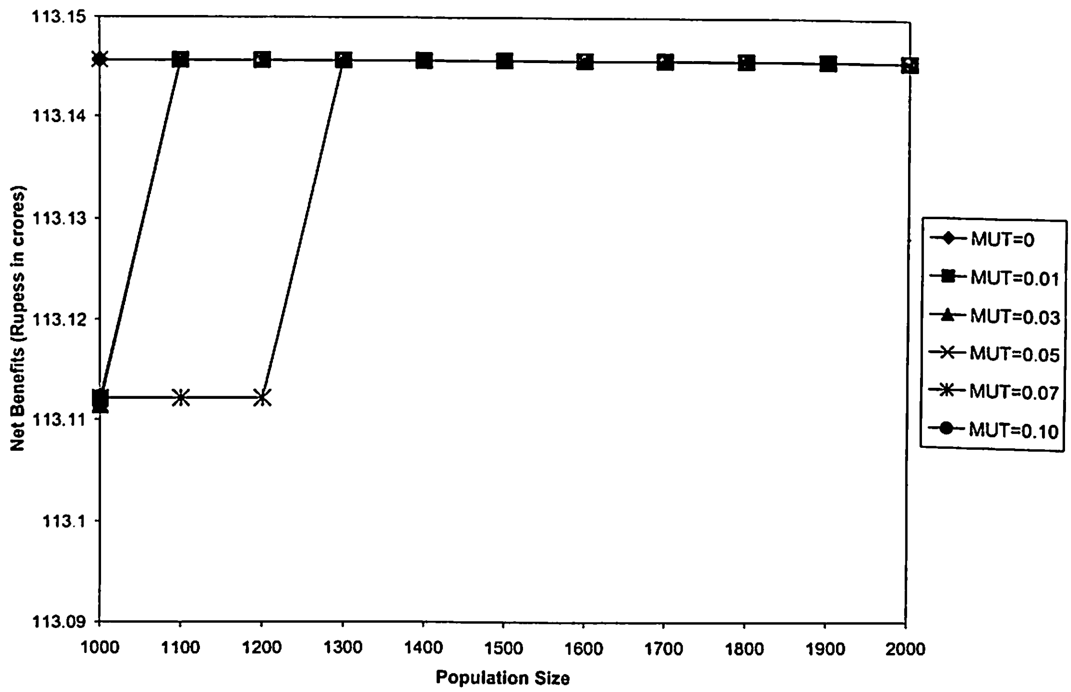

Fig. 6.13 Variation of net benefits for different mutation probabilities and population sizes (XR=0.90)

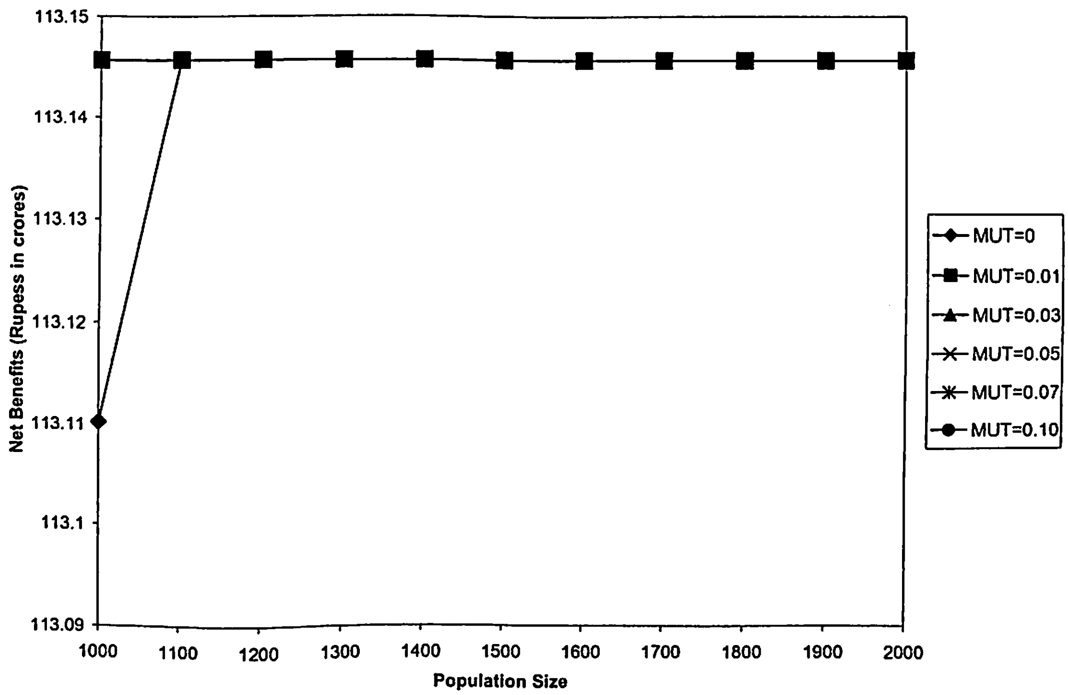

Fig. 6.14 Variation of net benefits for different mutation probabilities and population sizes (XR=0.95)

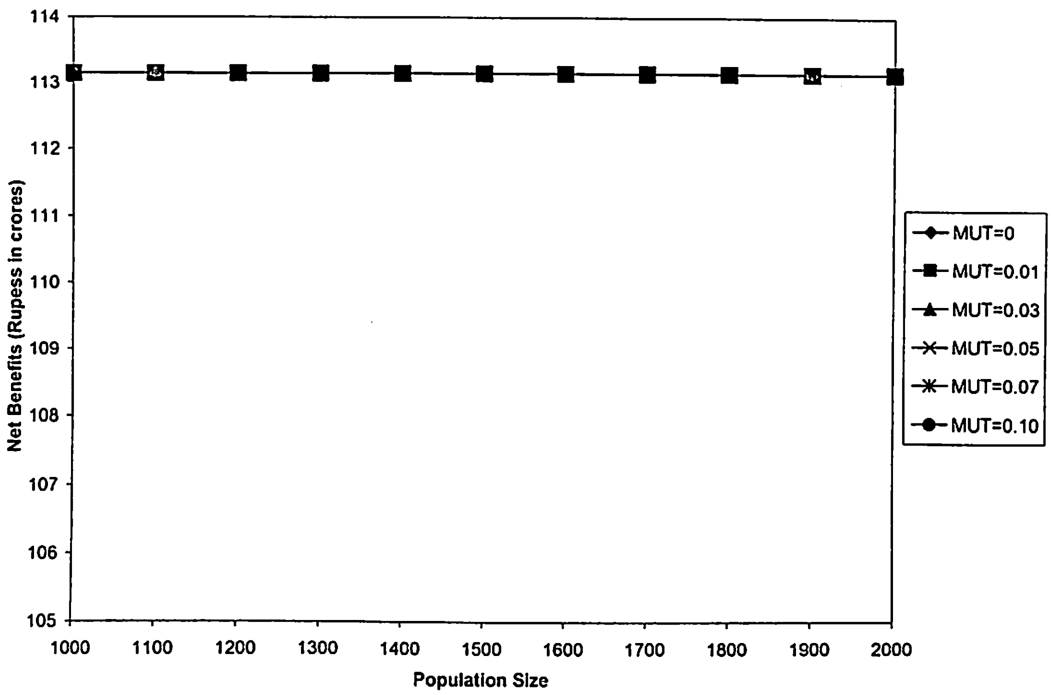

Fig. 6.15 Variation of net benefits for different mutation probabilities and population sizes (XR=1.0)

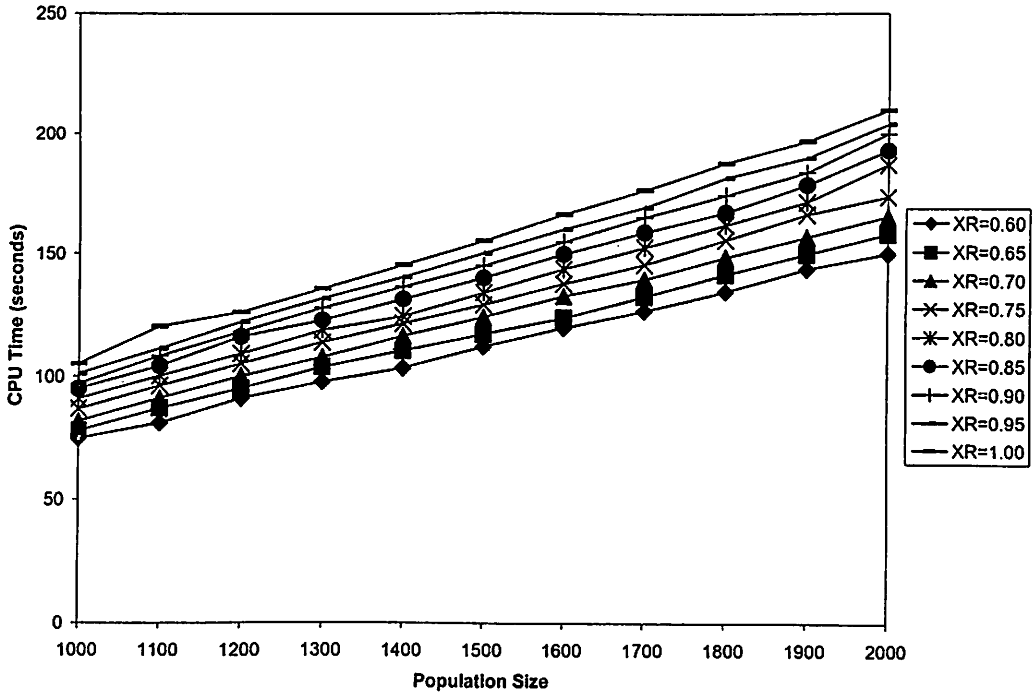

Fig. 6.16 CPU time variation for different crossover probability and population sizes (MUT=0.01)

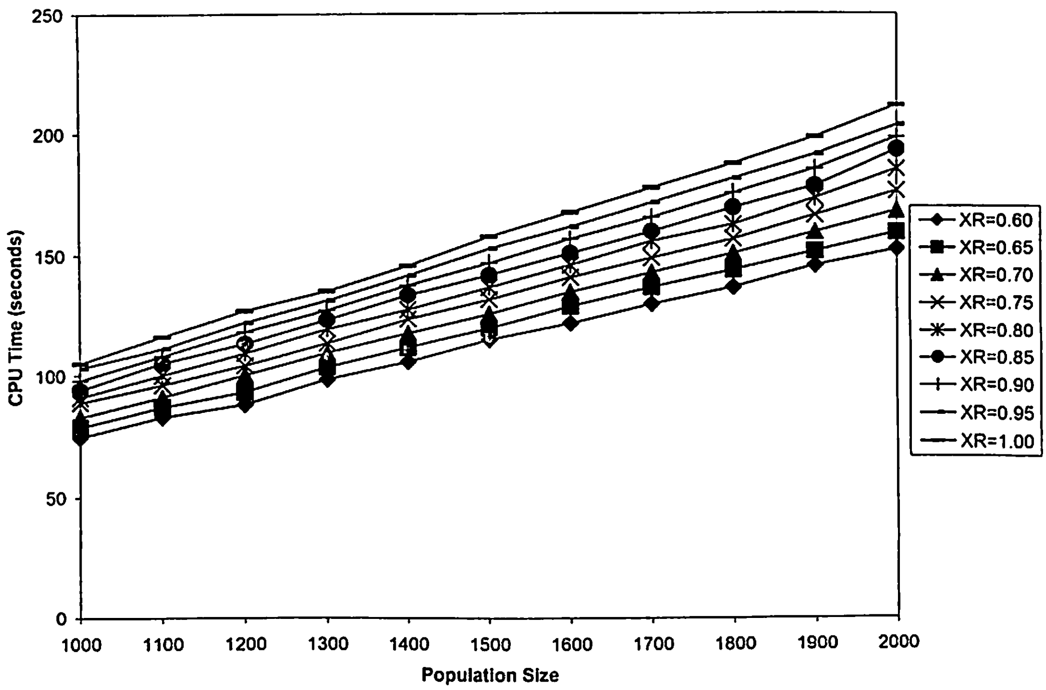

Fig. 6.17 CPU time variation for different crossover probability and population sizes (MUT=0.05)

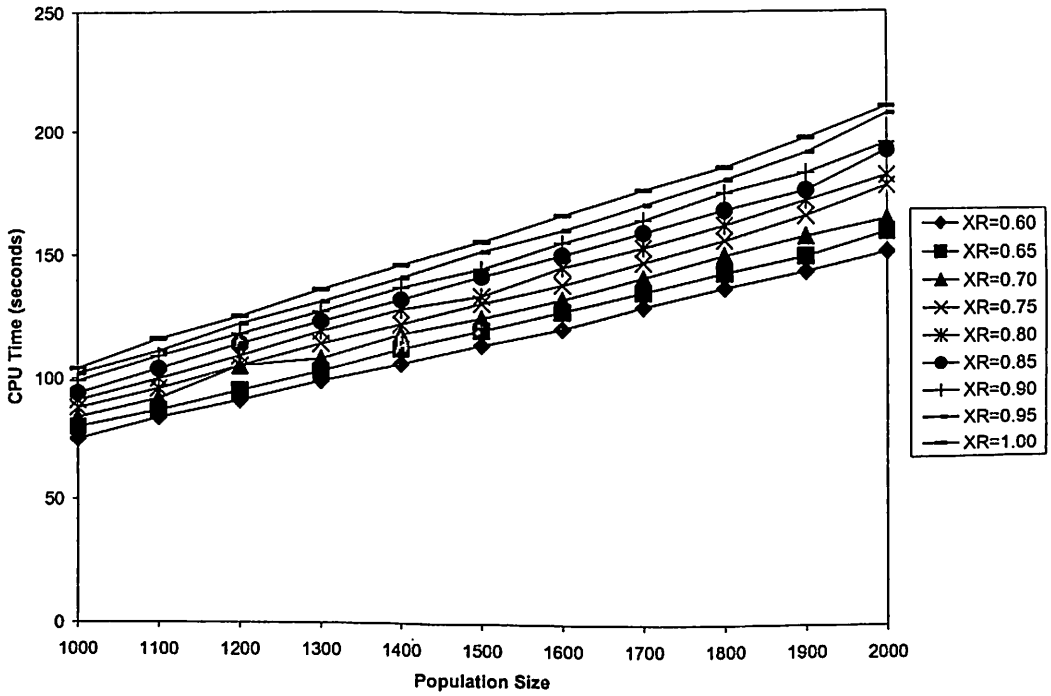

Fig. 6.18 CPU time variation for different crossover probability and population sizes (MUT=0.10)

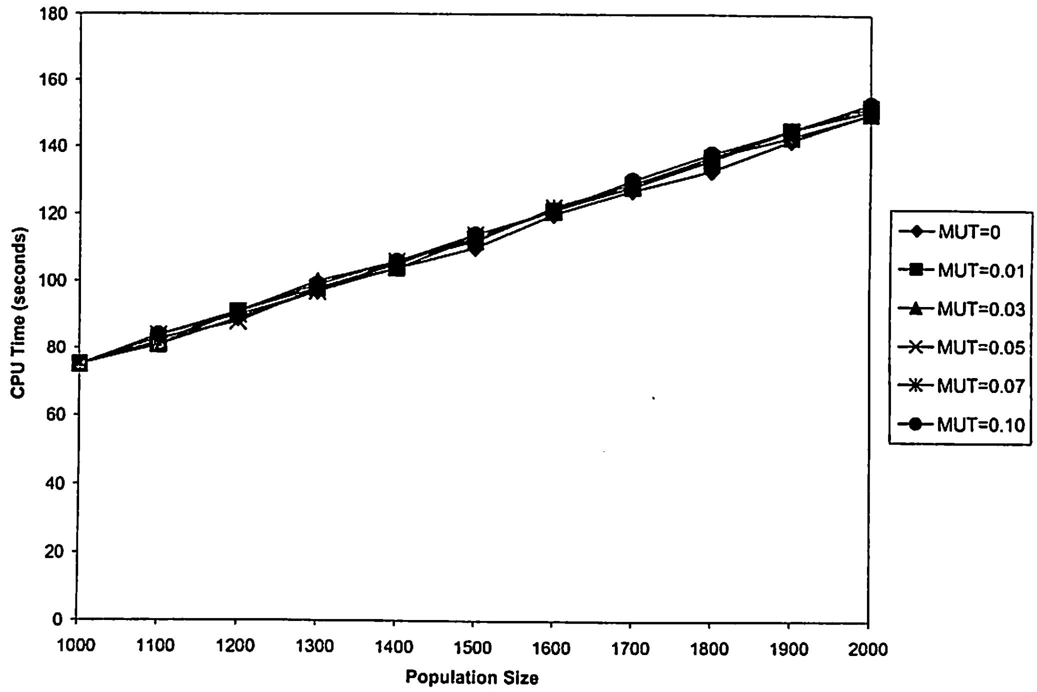

Fig. 6.19 CPU time variation for different mutation probability and population sizes (XR=0.60)

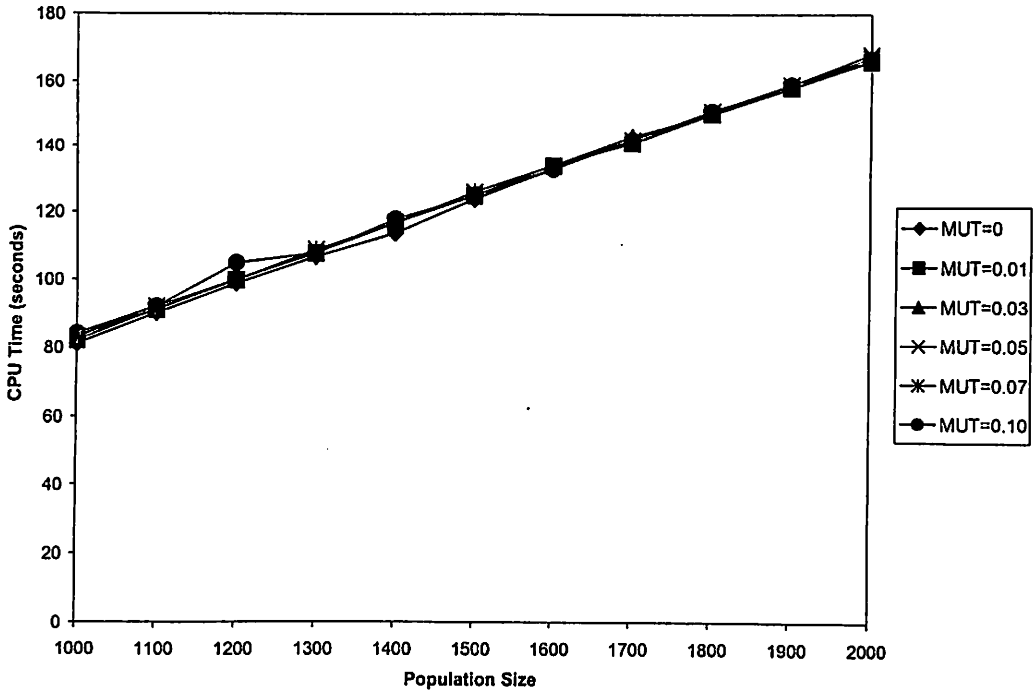

Fig. 6.20 CPU time variation for different mutation probability and population sizes (XR=0.80)

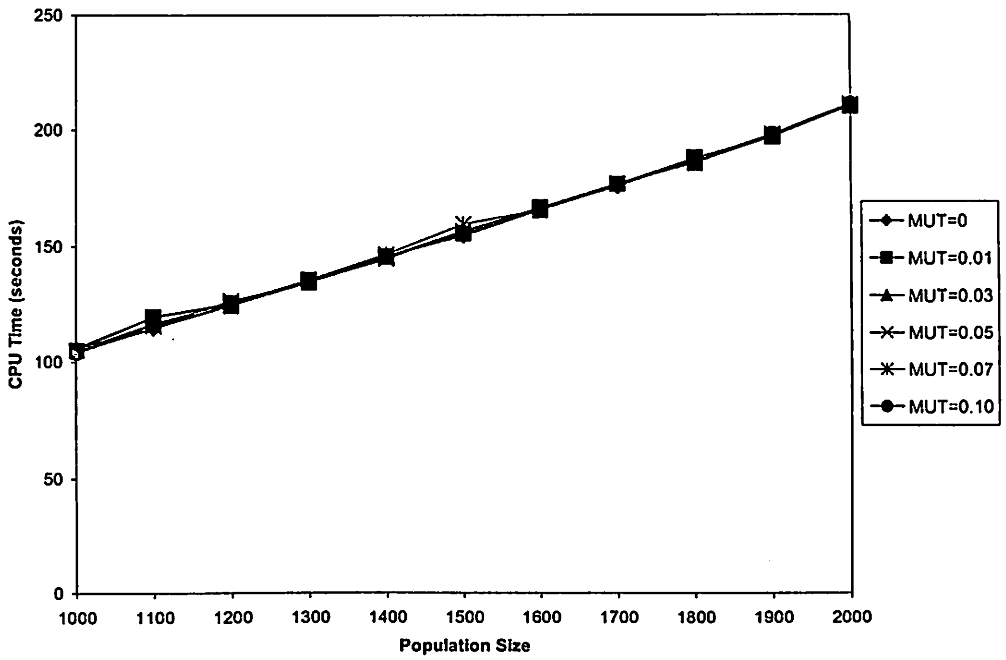

Fig. 6.21 CPU time variation for different mutation probability and population sizes (XR=1.0)

Type I - Variation of net benefits for different crossover probability and population size for various mutation probability values

- It is observed from Fig. 6.1 (MUT=0) that for POP=1000 and for various XR values (0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.00), there is a wide variation of net benefits (Rs.111.18 crores to Rs.113.15 crores). Even though, the population size has an effect, its trend is difficult to ascertain. The most interesting feature is as crossover probability is increasing, the net benefits are converging to a single value of Rs.113.15 crores for any value of population size. This convergence takes place at XR=0.85. From thereafter the values of net benefits are consistent.
- It is observed from Fig. 6.2 (MUT=0.01) that for POP=1000, the range of net benefits is from Rs.111.59 crores to Rs.113.15 crores. It is similar to the previous graph i.e., Fig 6.1 (MUT=0) in the context that the value of net benefits reaches consistent value of Rs.113.15 crores at XR=0.85 for all population sizes as before. At POP=1200, there is a very narrow range of net benefits varying from Rs.113.05 crores to Rs.113.15 crores.

- A similar trend is observed for Fig. 6.3 (MUT=0.03) in which the lower value of net benefits for POP=1000 is Rs.111.98 crores. The variation of net benefits narrows with the increase in population size (except for POP=1100, 1600, 1900 and 2000). The net benefits converge to a consistent value at crossover rate 0.85 and thereafter the value of net benefits remains same.
- A similar trend is observed from Fig. 6.4 (MUT=0.05) where the net benefits vary from Rs.111.52 crores to Rs.113.15 crores for POP=1000 and reach a consistent value of Rs.113.15 crores at crossover probability of 0.80 for any population size.
- A different trend is observed in case of MUT=0.07 (Fig. 6.5). In this case, the net benefits are in a very narrow range except for XR=0.60 and XR=0.65. The variation of net benefits is more at POP=1200 varying from Rs.111.64 crores to Rs.113.15 crores. The net benefits reach a consistent value Rs.113.15 crores at crossover probability of 0.95 for any population size with slight variation at POP=1900 and 2000.
- It is observed from Fig. 6.6 (MUT=0.10) that as the population size increases, the variation of net benefits gets narrower (neglecting minor exception at POP=1700). The net benefits reach a consistent value of Rs.113.15 crores at crossover probability of 0.95 for any population size similar to Fig. 6.5 (MUT=0.07).
- It is observed from Fig. 6.1 (MUT=0) to Fig 6.6 (MUT=0.10) and above inferences that crossover probability XR and population size POP have a significant effect on the net benefits for various mutation probability MUT values.

Type II - Variation of net benefits for different mutation probability and population size for various crossover probability values

- It is observed from Fig. 6.7 (XR=0.60), Fig. 6.8 (XR=0.65) that there is no distinct pattern, even though there is an effect of increase in population size for various mutation probability values.
- It is observed from Fig. 6.9 (XR=0.70), Fig. 6.10 (XR=0.75) and Fig. 6.11 (XR=0.80) that net benefits are converging to a consistent value of Rs.113.15 crores at population size 1900, 1600 and 1300 respectively irrespective of mutation probability values.

- Similarly, it is observed from Fig. 6.12 (XR=0.85), Fig. 6.13 (XR=0.90) and Fig. 6.14 (XR=0.95) that net benefits reach a consistent value of Rs.113.15 crores at population size 1600, 1300 and 1100 irrespective of mutation probability values.
- It is observed from Fig. 6.15 (XR=1.00) that net benefits are the same (Rs.113.15 crores) irrespective of population size and mutation probability values.

Type III - CPU time variation for different population size and crossover probability for various mutation probability values

- It is observed from Fig. 6.16 (MUT=0.01), Fig. 6.17 (MUT=0.05), Fig. 6.18 (MUT=0.10) that the variation of CPU time shows an increasing trend with population size for various crossover probability values for a given mutation probability value of 0.01, 0.05 and 0.10.
- Less CPU time is observed for XR=0.60 and high value is observed for XR=1.0 indicating the increase of CPU time with increase of XR value.
- It is also observed that CPU time increases with the XR value and is independent of population size. For example, in Fig. 6.18 (MUT=0.10) for POP=2000, CPU time varies from 151 seconds for XR=0.60 to 210 seconds for XR=1.0.

Type IV - CPU time variation for different population size and mutation probability for various crossover probability values

- It is observed from Fig. 6.19 (XR=0.60), Fig. 6.20 (XR=0.80), Fig. 6.21 (XR=1.0) that for a population size and a given XR value, no significant effect of mutation probability is observed on CPU time.
- It is also observed that CPU time increases with population size. For example, in Fig. 6.21 (XR=1.0) for MUT=0.01, CPU time varies from 104 seconds for POP=1000 to 211 seconds for POP=2000.

Inferences:

- As crossover probability increases, the net benefits are converging to a value of Rs.113.15 crores for any population size and a given mutation probability value.

- ❖ Variation of net benefits reduces with increase in population size for any crossover and mutation probability value.
- ❖ Increase of CPU time requirement is observed with increase of crossover probability value for any population size.
- ❖ No significant effect of mutation probability is observed on CPU time requirement for any population size.
- ❖ CPU time requirement increases with increase in population size for any crossover and mutation probability value.

6.3.3.2 Differential Evolution (DE)

The number of generations and accuracy between two successive generations (fixed as 3000 and 10^{-7} respectively) employed earlier in the original problem are used. The other parameters used in the study are population size (NP) varied from 1100 to 2000 with an increment of 100 (10 levels), crossover constant (CR) from 0.5 to 1.0 with an increment 0.1 (6 levels), weighting factor (F) from 0.5 to 1.0 with an increment 0.1 (6 levels) and ten different strategies DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp (Onwubolu and Babu, 2004; Price and Storn, 2005). The resulting number of combinations is $10 \times 6 \times 6 \times 10 = 3600$.

The program is run for 3600 combinations to determine the optimal set of parameters as explained in Section 6.3.3.1. The program determines the optimal set of parameters for each DE strategy and the best DE strategy is found in a similar manner based on maximum net benefits and CPU time requirement. The optimal set of parameters for each strategy is presented in Table 6.15. It is observed from Table 6.15 that the strategies DE/best/1/bin, DE/best/2/bin, DE/rand-to-best/1/bin, DE/best/1/exp and DE/rand-to-best/1/exp achieved the maximum net benefits of Rs.113.15 crores. To decide on the best strategy out of these, CPU time requirements of these strategies are compared. It is found that the best strategy is DE/rand-to-best/1/bin having optimal set of parameters as NP=1100, CR=0.9, F=0.6. This yields maximum net benefits of Rs.113.15 crores taking least CPU time of 102.13 seconds based on PC with Pentium IV 2.4GHz/256MB

RAM/40GB HDD configuration. Effect of variation of each parameter is shown in the form of graphs from Fig. 6.22 to 6.62. The graphs are classified into five types and they are:

- Type I - Fig. 6.22 to Fig. 6.31 - Presents the variation of net benefits for different population sizes (1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) and ten strategies DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp for various crossover rates CR (0.5, 0.6, 0.7, 0.8, 0.9, 1.0) with a specific weighting factor F of 0.5.
- Type II - Fig. 6.32 to Fig. 6.41 – Presents the variation of net benefits for different population sizes (1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) and ten strategies DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp for various weighting factor F (0.5, 0.6, 0.7, 0.8, 0.9, 1.0) with a specific crossover rate CR of 1.0.
- Type III - Fig. 6.42 - Presents the variation of net benefits for ten different DE strategies namely, DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp for various combinations [(NP=2000, CR=1.0, F=0.5), (NP=1800, CR=1.0, F=0.7), (NP=1400, CR=1.0, F=0.5), (NP=1300, CR=1.0, F=0.5), (NP=1100, CR=0.9, F=0.6), (NP=1500, CR=1.0, F=0.5), (NP=1600, CR=1.0, F=0.7), (NP=1100, CR=0.9, F=0.5), (NP=2000, CR=1.0, F=0.7)]. The combinations used above are the optimal set of parameters obtained for the respective strategies as presented in Table 6.15.
- Type IV - Fig. 6.43 to Fig. 6.52 - Presents the CPU time variation for different population sizes (1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) and ten strategies DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp for various crossover rates CR (0.5, 0.6, 0.7, 0.8, 0.9, 1.0) with a specific weighting factor F of 0.5.

➢ Type V - Fig. 6.53 to Fig. 6.62 - Presents the CPU time variation for different population sizes (1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000) and ten strategies DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp for various weighting factors F (0.5, 0.6, 0.7, 0.8, 0.9, 1.0) with a specific crossover rate CR of 1.0.

Table 6.15 Optimal set of parameters for all ten DE strategies

Strategy	NP	CR	F	Net Benefits (Rupees in crores)	Time Taken* (seconds)
DE/rand/1/bin	2000	1.00	0.50	112.95	179.14
DE/best/1/bin	1800	1.00	0.70	113.15	160.75
DE/best/2/bin	1400	1.00	0.50	113.15	127.48
DE/rand/2/bin	1300	1.00	0.50	112.32	119.22
DE/rand-to-best/1/bin	1100	0.90	0.60	113.15	102.13
DE/rand/1/exp	1500	1.00	0.50	113.10	136.50
DE/best/1/exp	1600	1.00	0.70	113.15	146.25
DE/best/2/exp	1500	1.00	0.50	112.97	140.09
DE/rand/2/exp	1100	0.90	0.50	112.77	63.91
DE/rand-to-best/1/exp	2000	1.00	0.70	113.15	182.05

* Based on PC with Penitum IV 2.4GHz/256MB RAM/40GB HDD

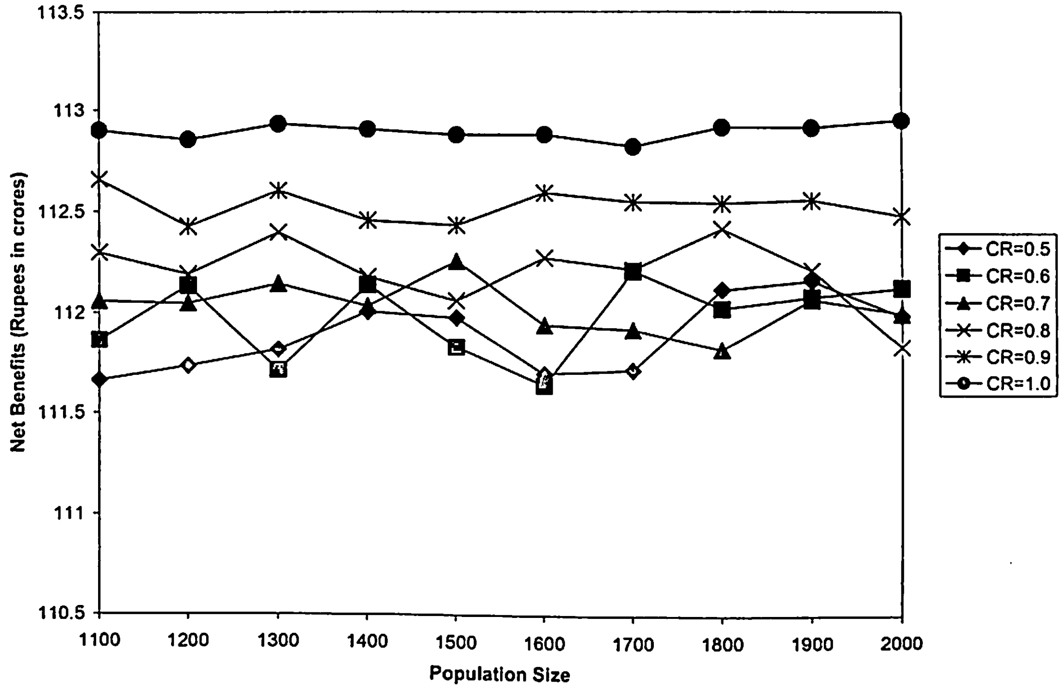

Fig. 6.22 Variation of net benefits for different crossover constant and population sizes (DE/rand/1/bin, F=0.5)

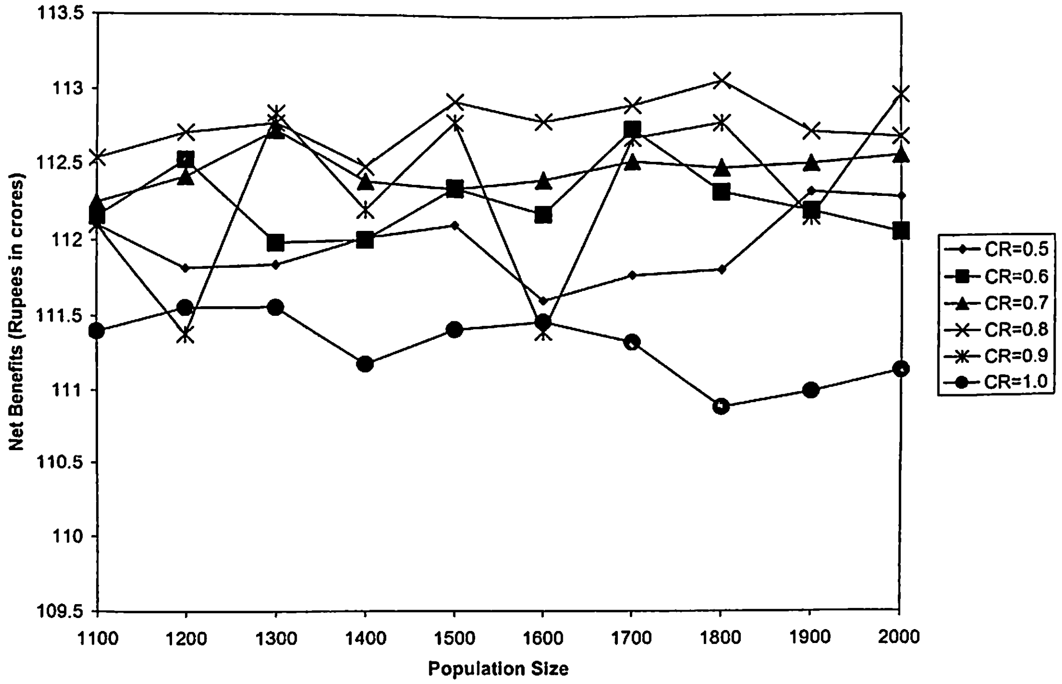

Fig. 6.23 Variation of net benefits for different crossover constant and population sizes (DE/best/1/bin, F=0.5)

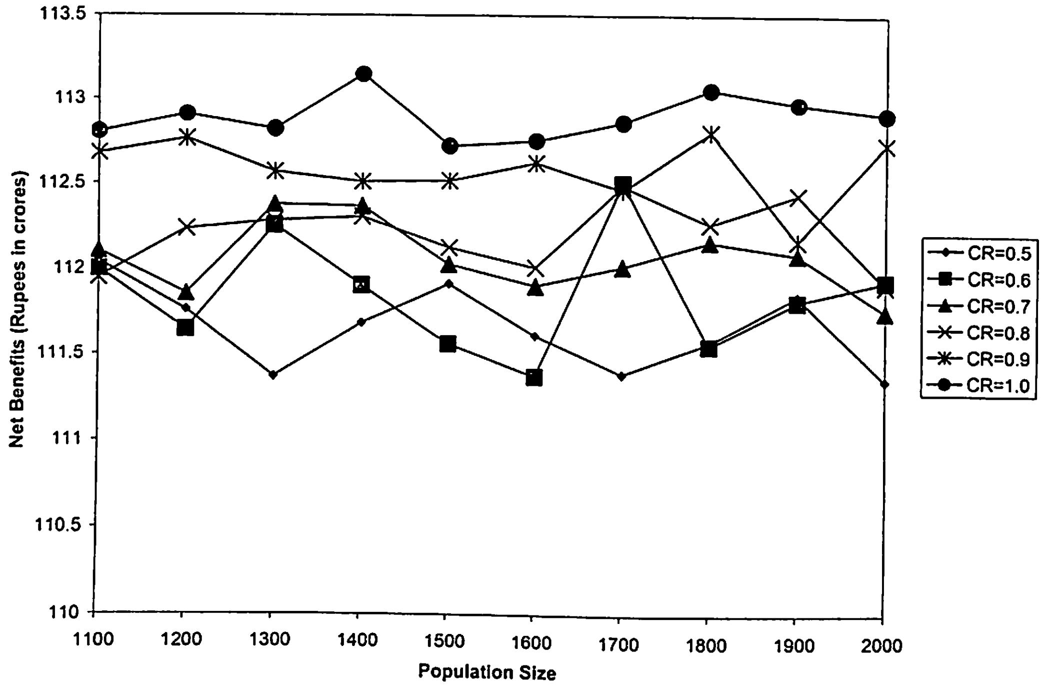

Fig. 6.24 Variation of net benefits for different crossover constant and population sizes (DE/best/2/bin, F=0.5)

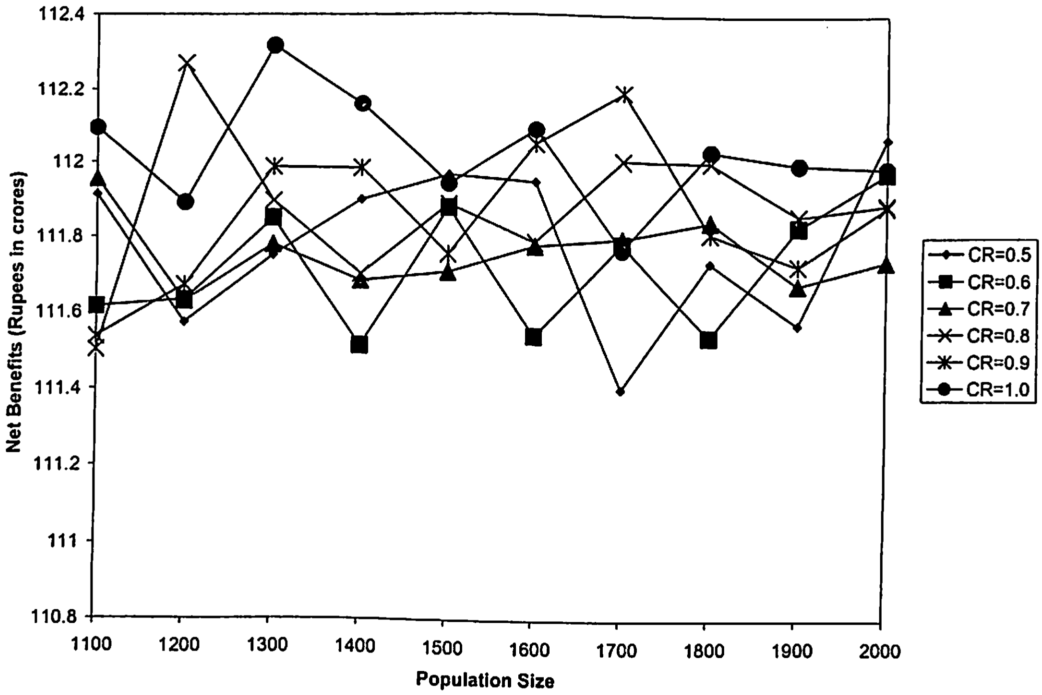

Fig. 6.25 Variation of net benefits for different crossover constant and population sizes (DE/rand/2/bin, F=0.5)

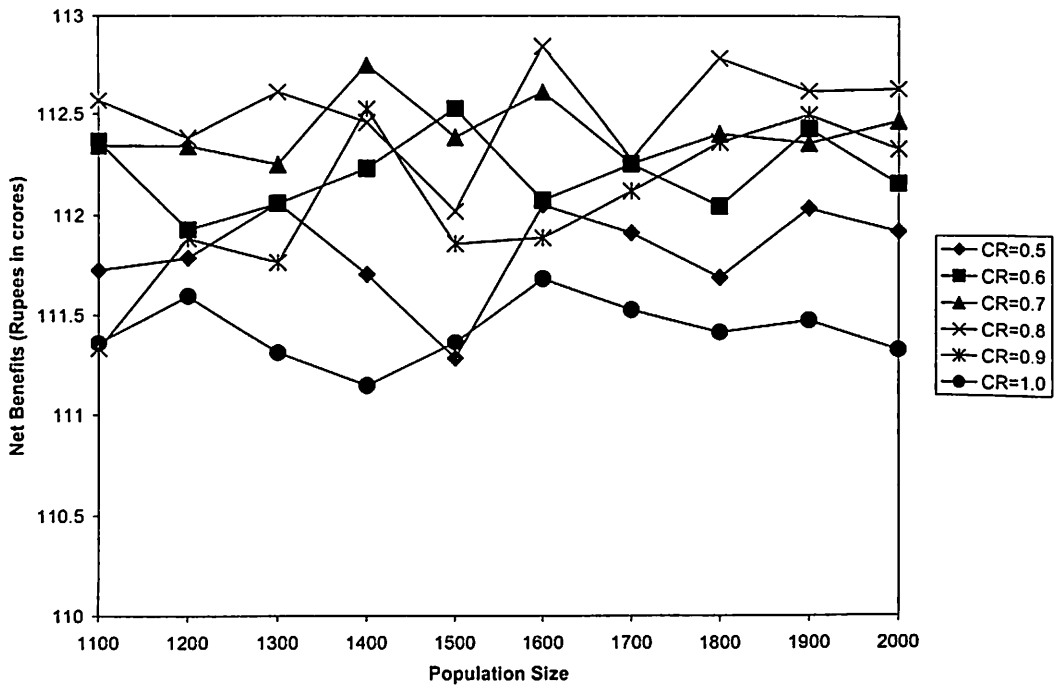

Fig. 6.26 Variation of net benefits for different crossover constant and population sizes (DE/rand-to-best/1/bin, F=0.5)

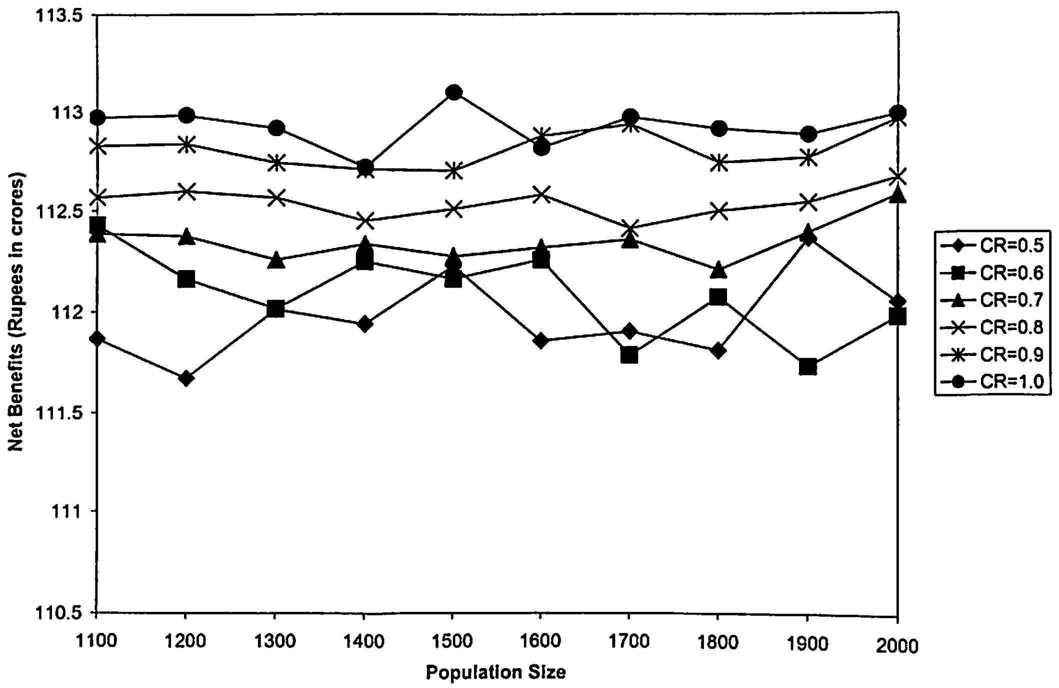

Fig. 6.27 Variation of net benefits for different crossover constant and population sizes (DE/rand/1/exp, F=0.5)

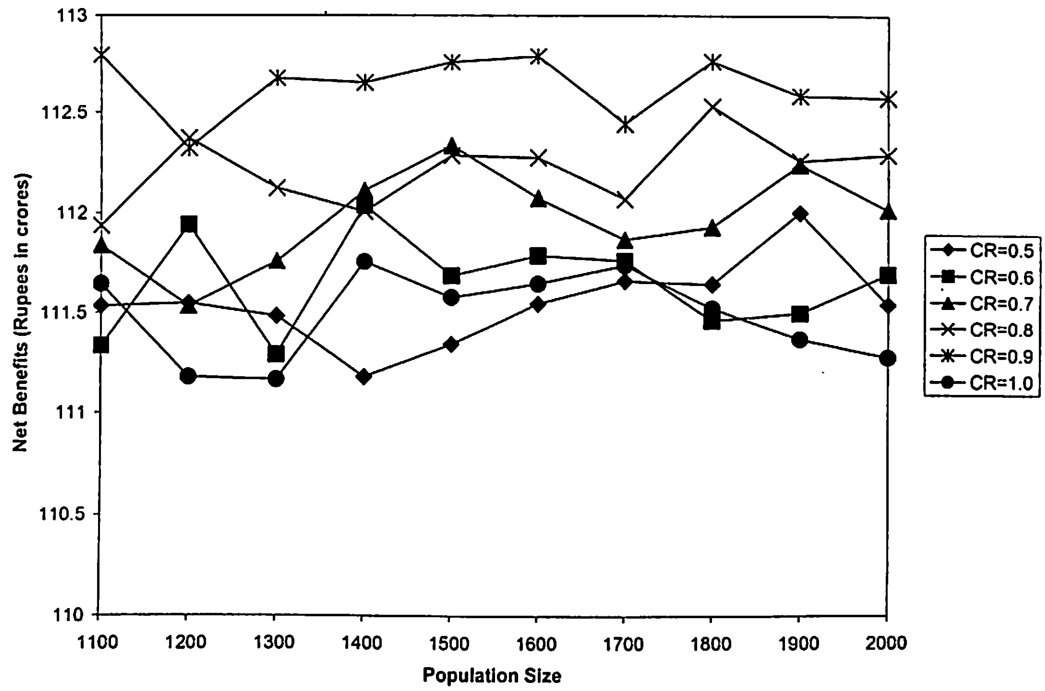

Fig. 6.28 Variation of net benefits for different crossover constant and population sizes (DE/best/1/exp, F=0.5)

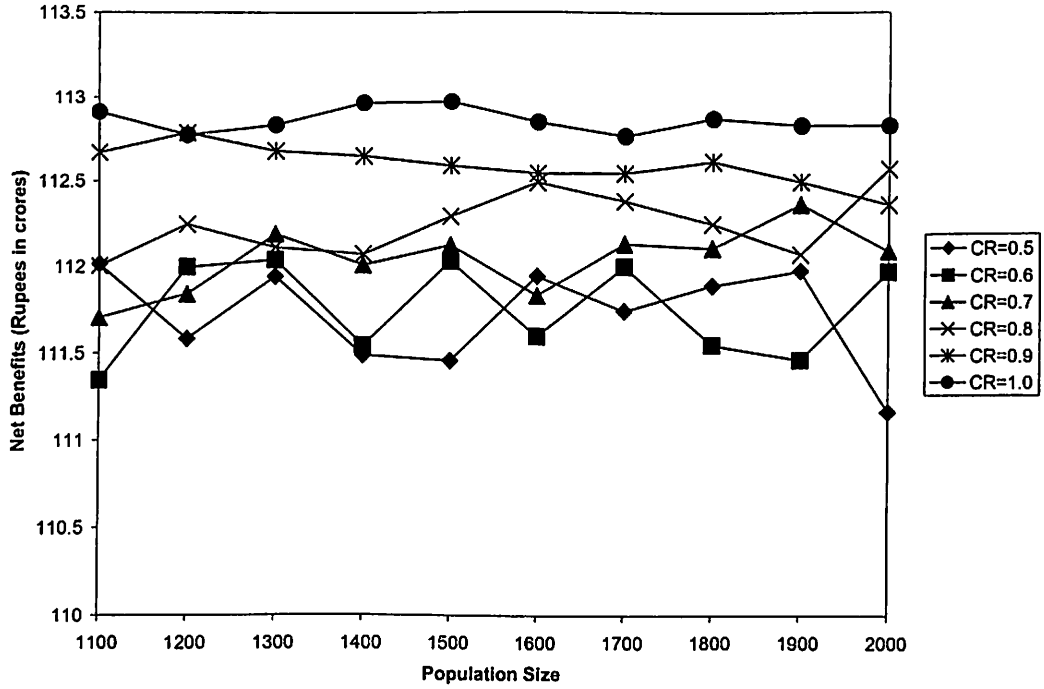

Fig. 6.29 Variation of net benefits for different crossover constant and population sizes (DE/best/2/exp, F=0.5)

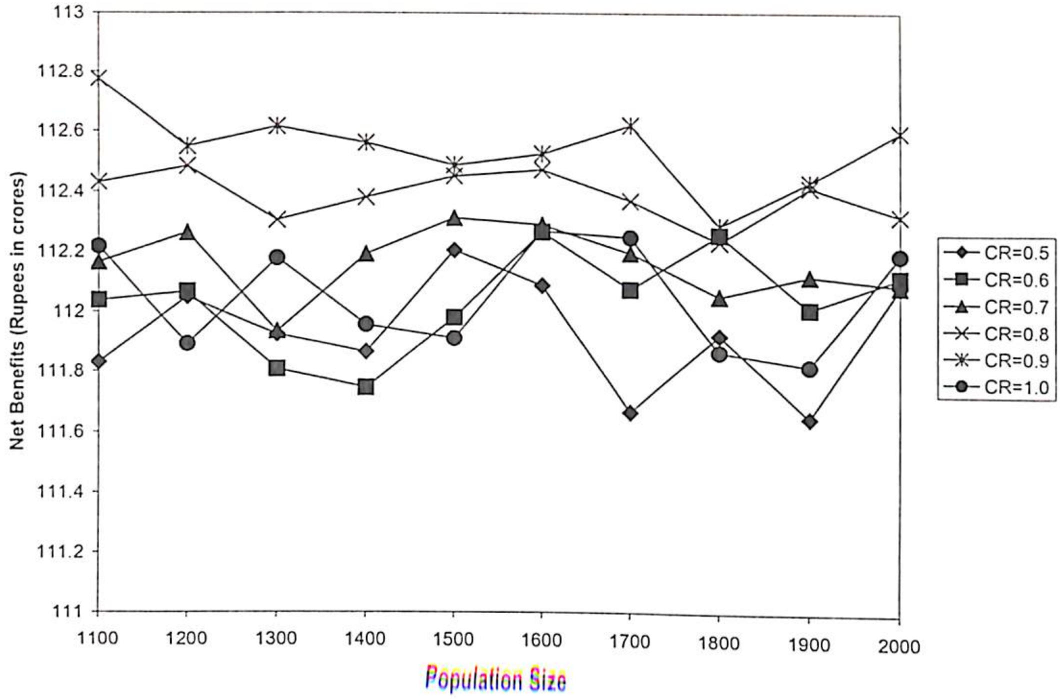

Fig. 6.30 Variation of net benefits for different crossover constant and population sizes (DE/rand/2/exp, F=0.5)

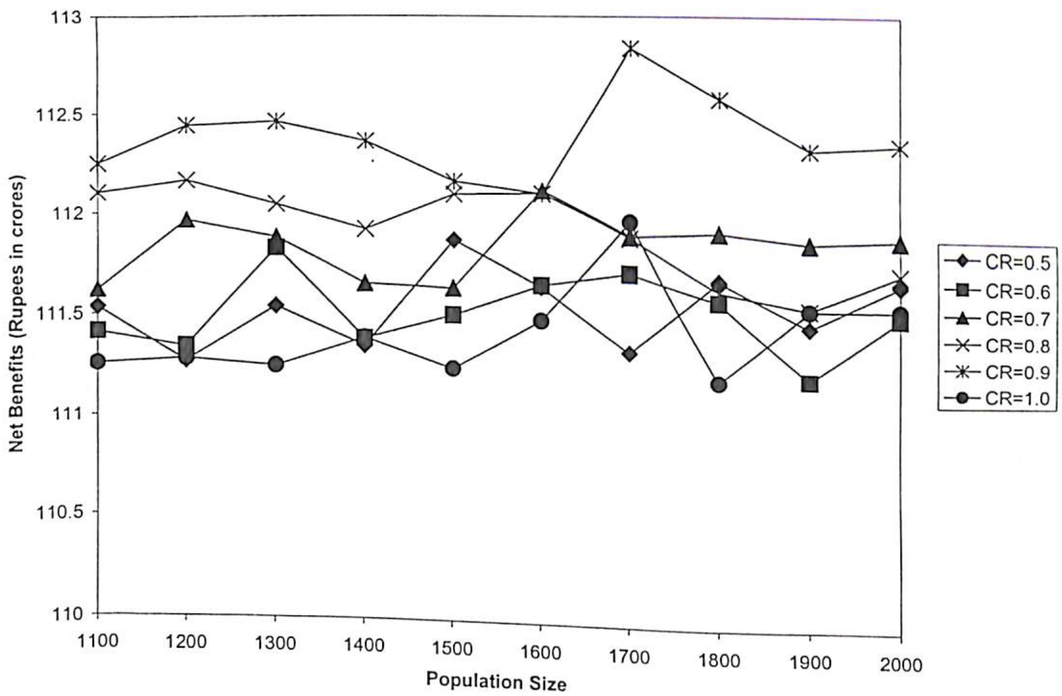

Fig. 6.31 Variation of net benefits for different crossover constant and population sizes (DE/rand-to-best/1/exp, F=0.5)

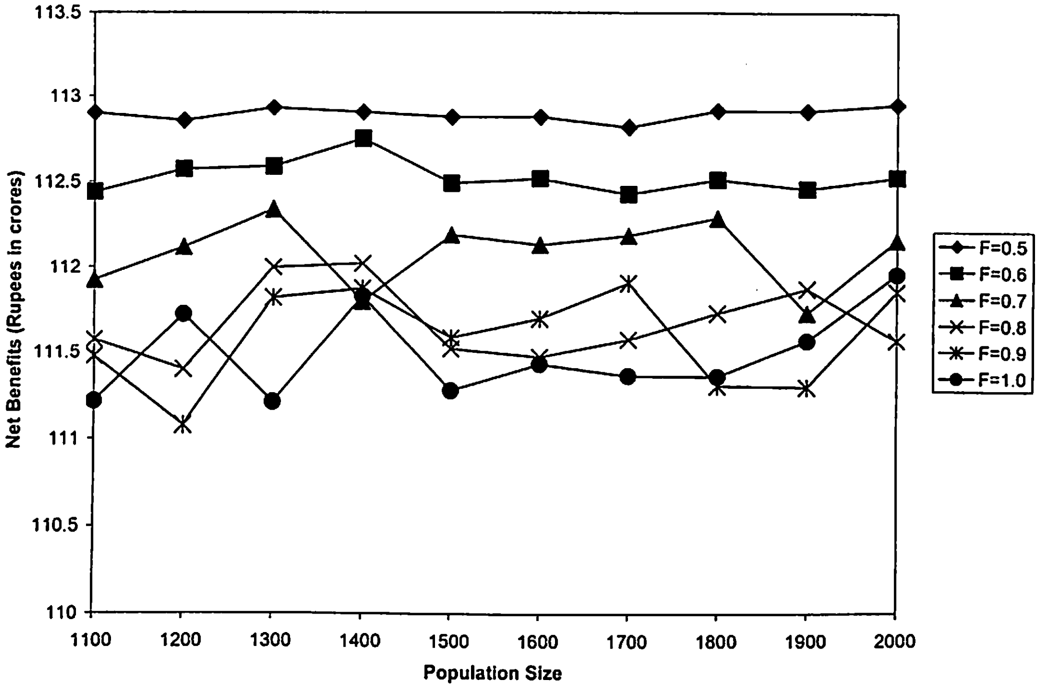

Fig. 6.32 Variation of net benefits for different weighting factor and population sizes (DE/rand/1/bin, CR=1.0)

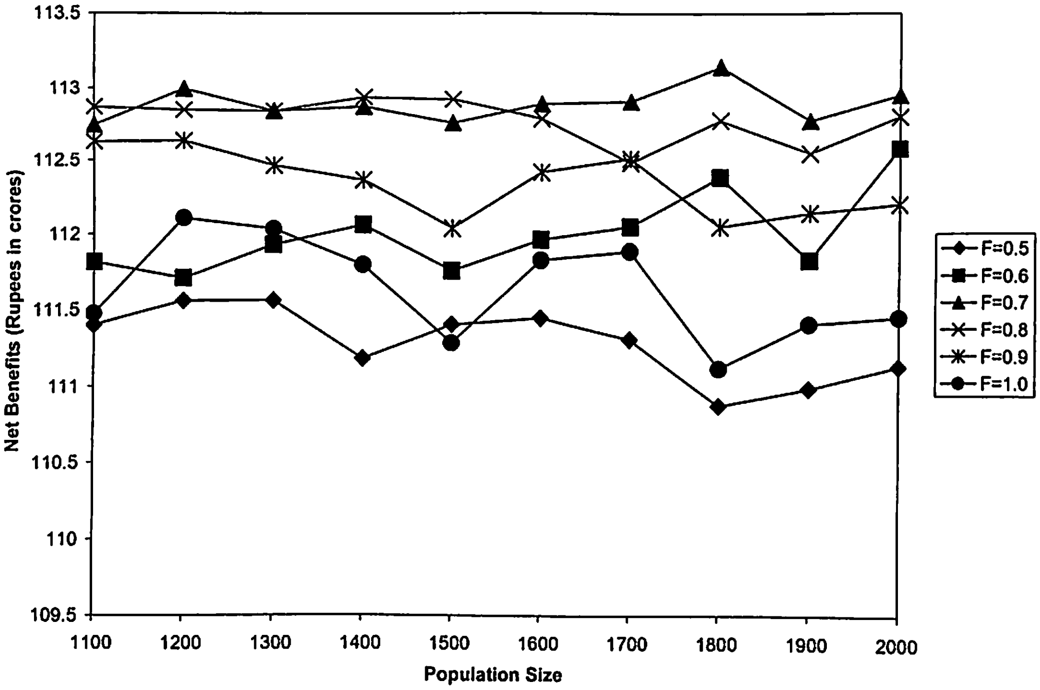

Fig. 6.33 Variation of net benefits for different weighting factor and population sizes (DE/best/1/bin, CR=1.0)

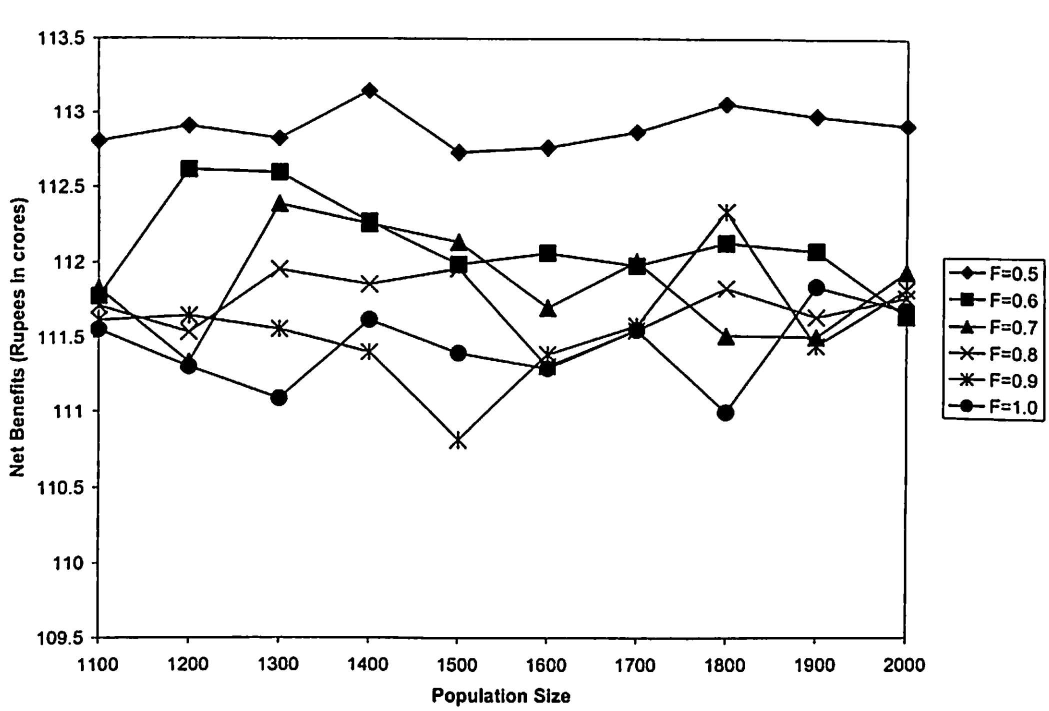

Fig. 6.34 Variation of net benefits for different weighting factor and population sizes (DE/best/2/bin, CR=1.0)

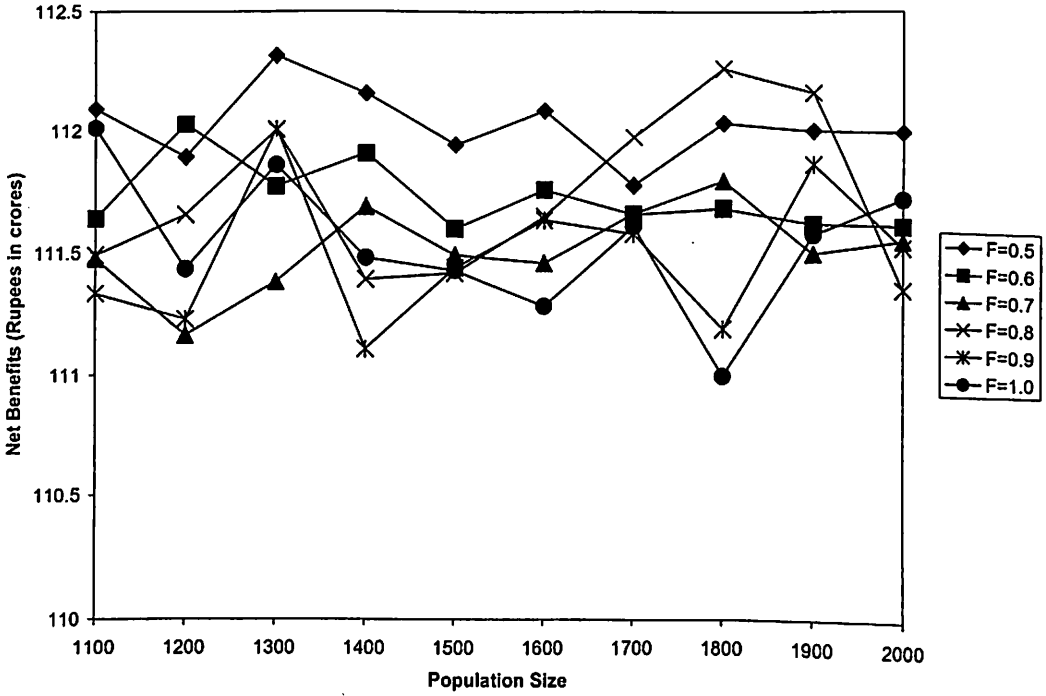

Fig. 6.35 Variation of net benefits for different weighting factor and population sizes (DE/rand/2/bin, CR=1.0)

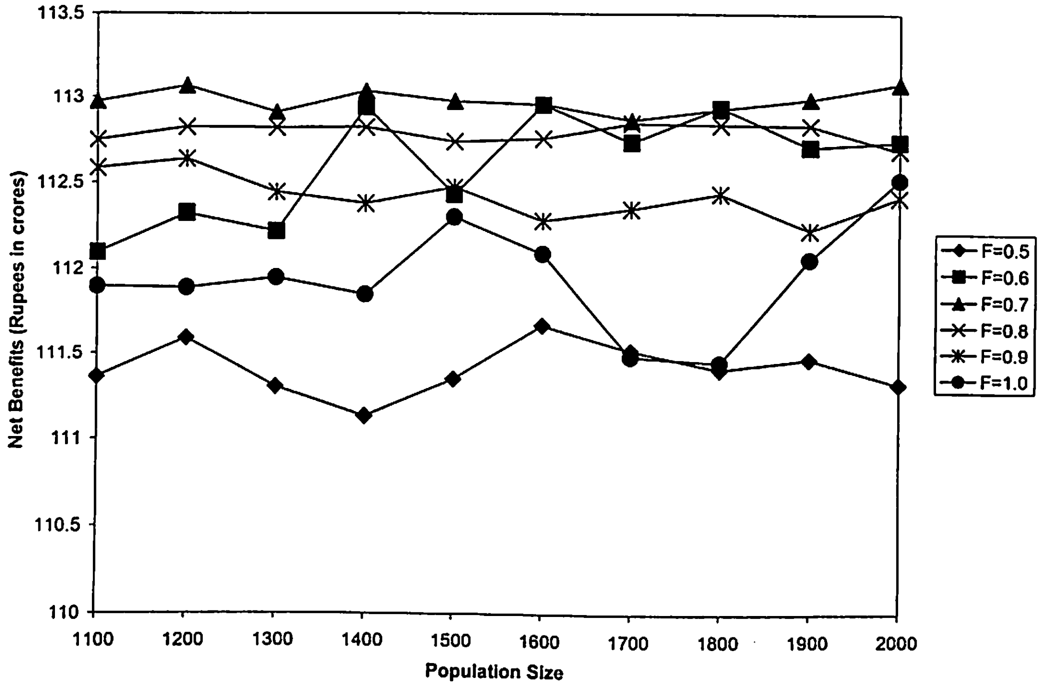

Fig. 6.36 Variation of net benefits for different weighting factor and population sizes (DE/rand-to-best/1/bin, CR=1.0)

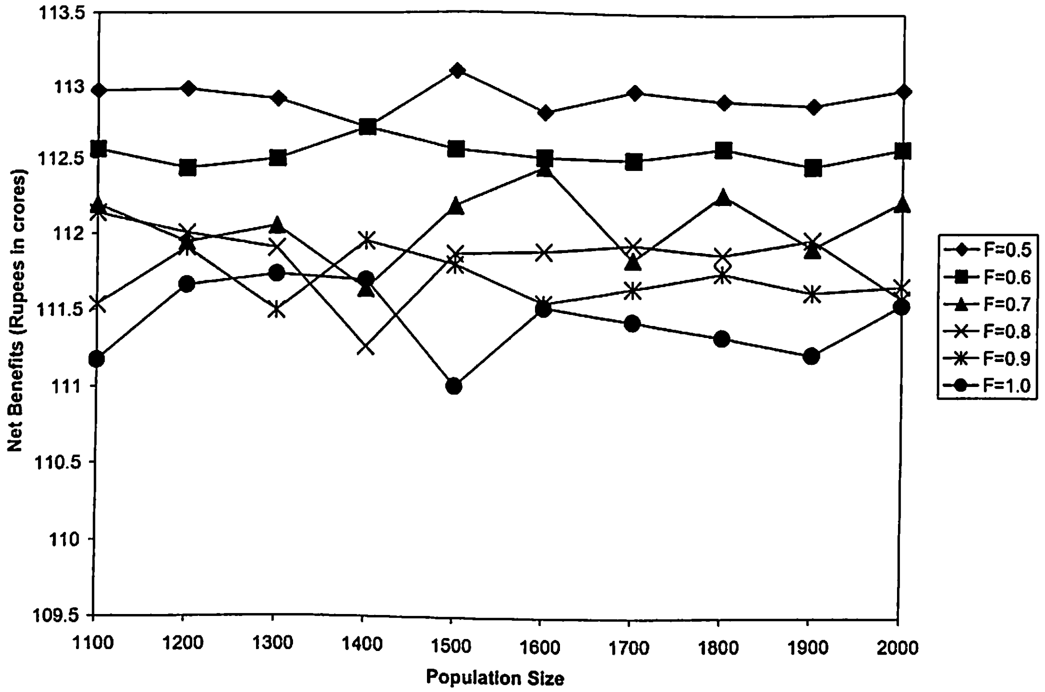

Fig. 6.37 Variation of net benefits for different weighting factor and population sizes (DE/rand/1/exp, CR=1.0)

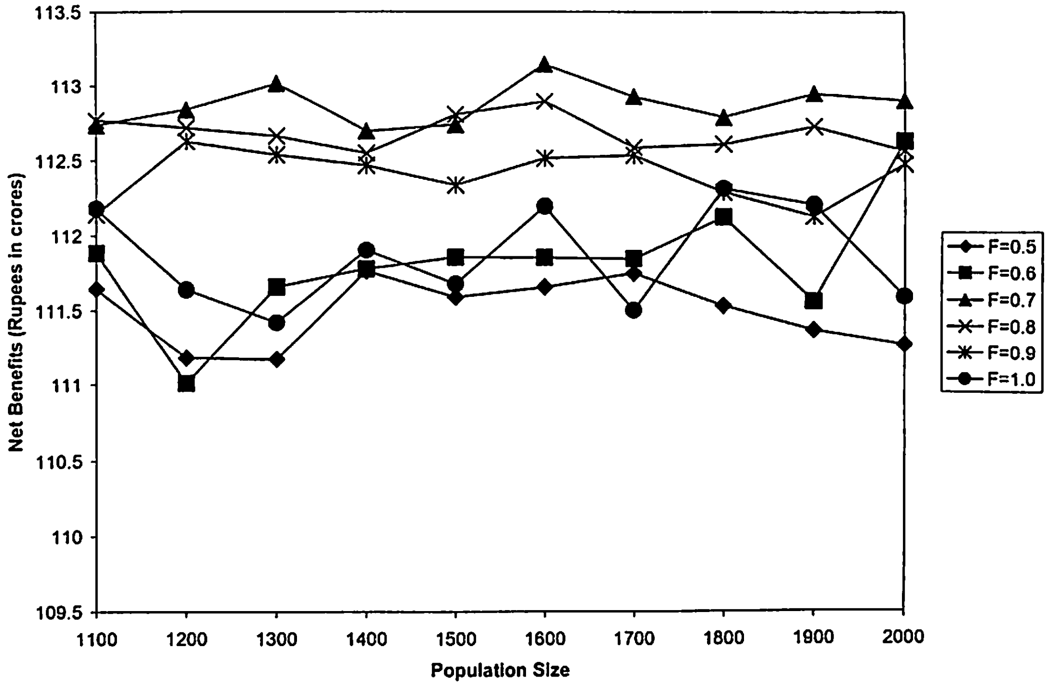

Fig. 6.38 Variation of net benefits for different weighting factor and population sizes (DE/best/1/exp, CR=1.0)

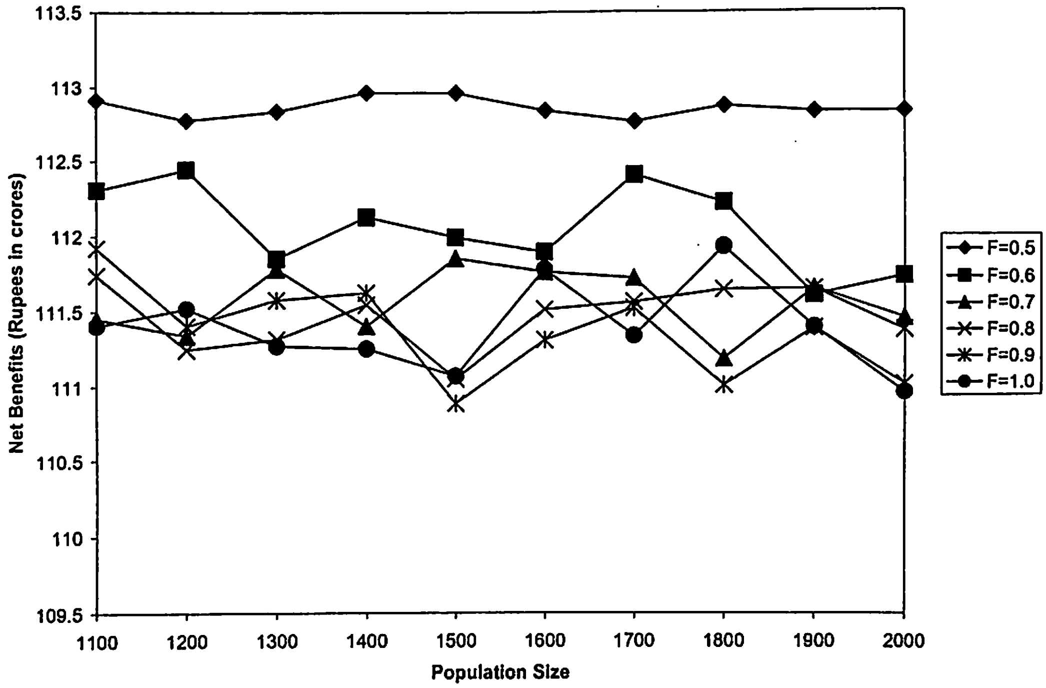

Fig. 6.39 Variation of net benefits for different weighting factor and population sizes (DE/best/2/exp, CR=1.0)

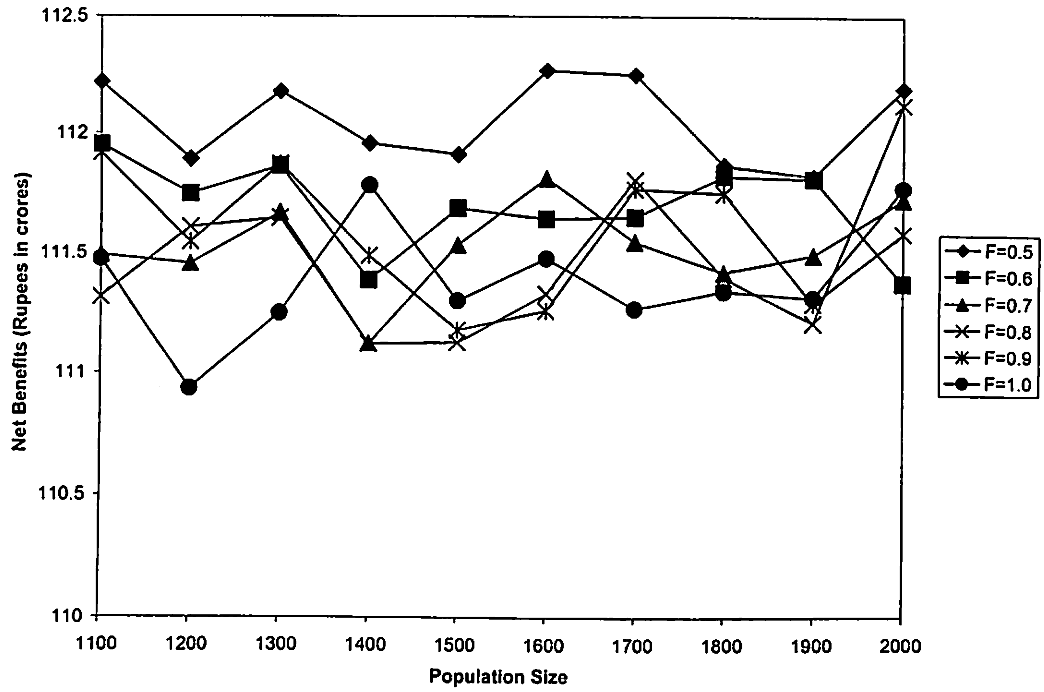

Fig. 6.40 Variation of net benefits for different weighting factor and population sizes (DE/rand/2/exp, CR=1.0)

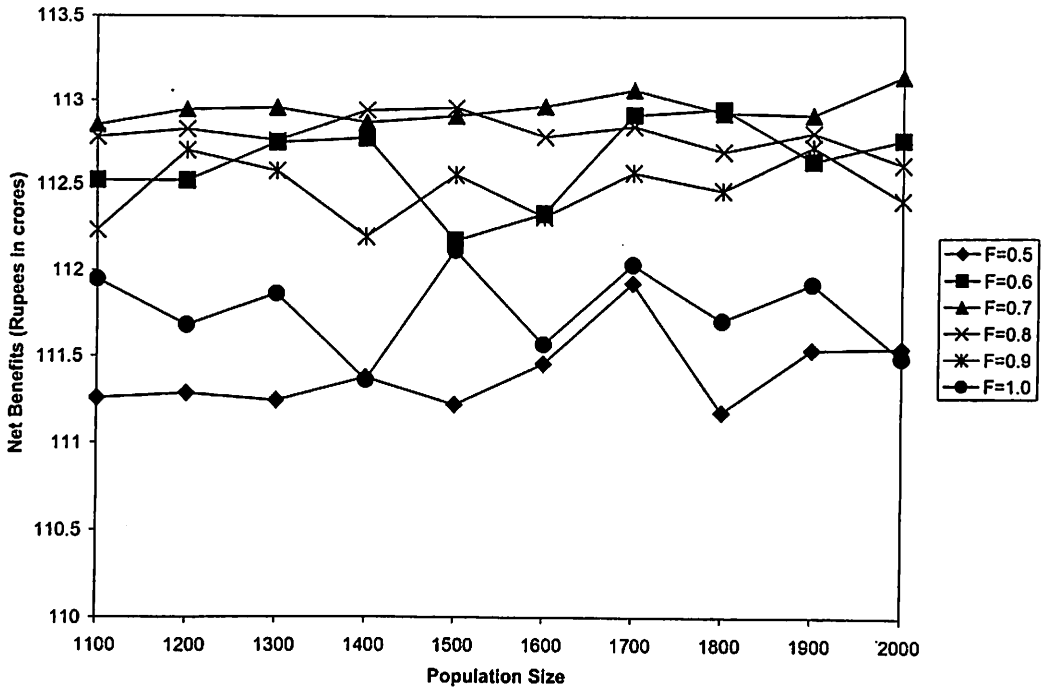

Fig. 6.41 Variation of net benefits for different weighting factor and population sizes (DE/rand-to-best/1/exp, CR=1.0)

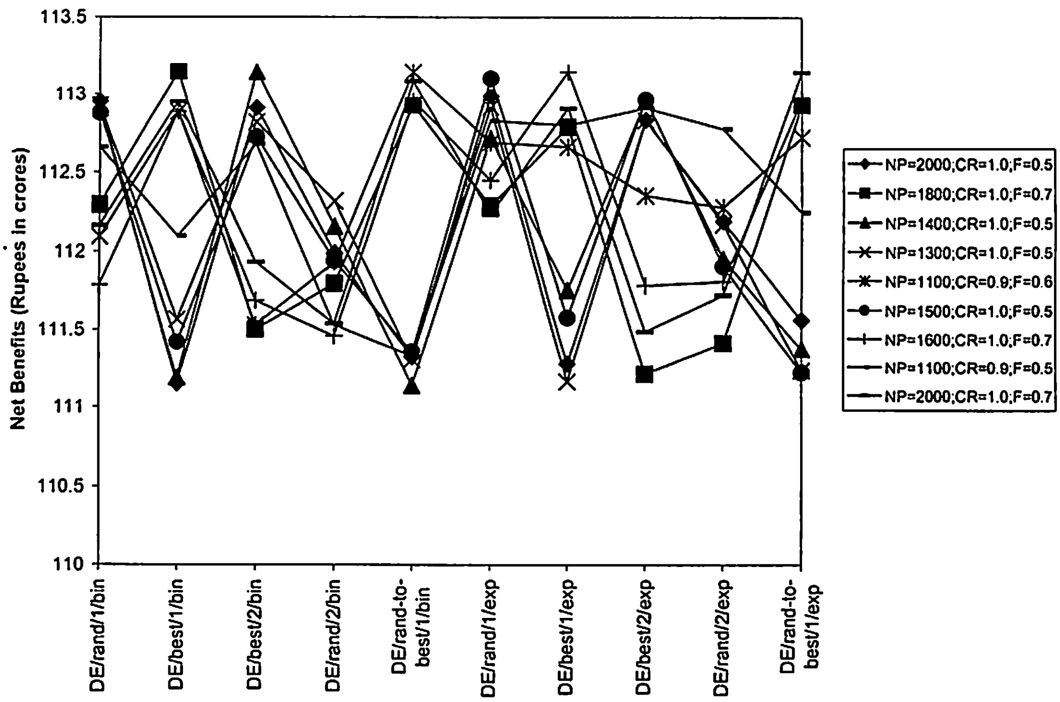

Fig. 6.42 Variation of net benefits for a sample set of parameters NP, CR and F for 10 strategies

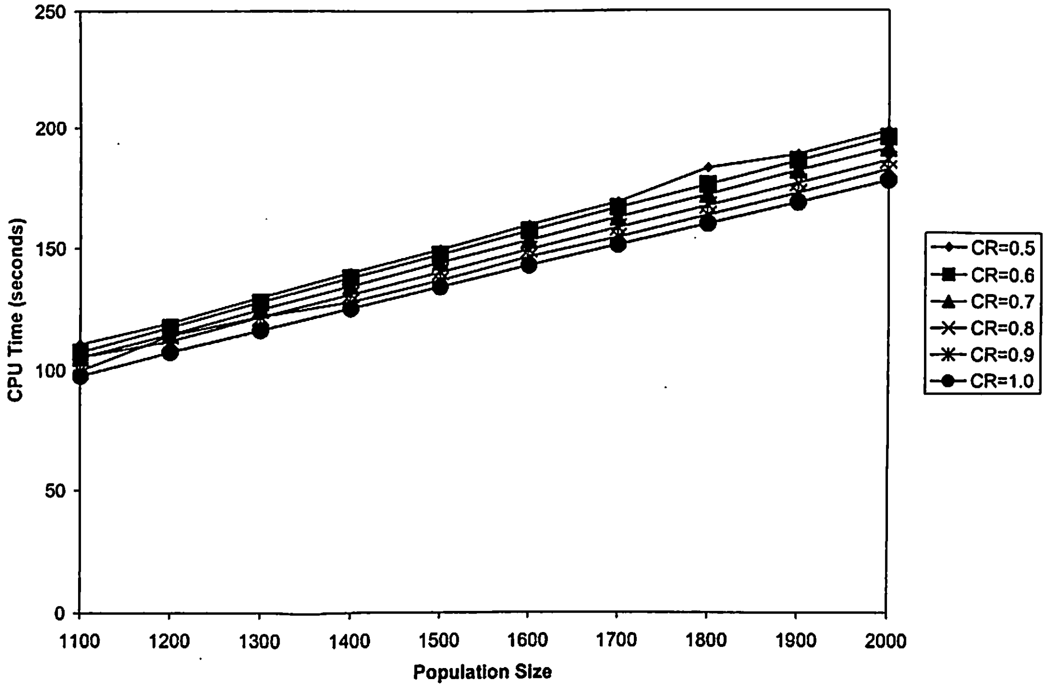

Fig. 6.43 CPU time variation for different crossover constant and population sizes (DE/rand/1/bin, F=0.5)

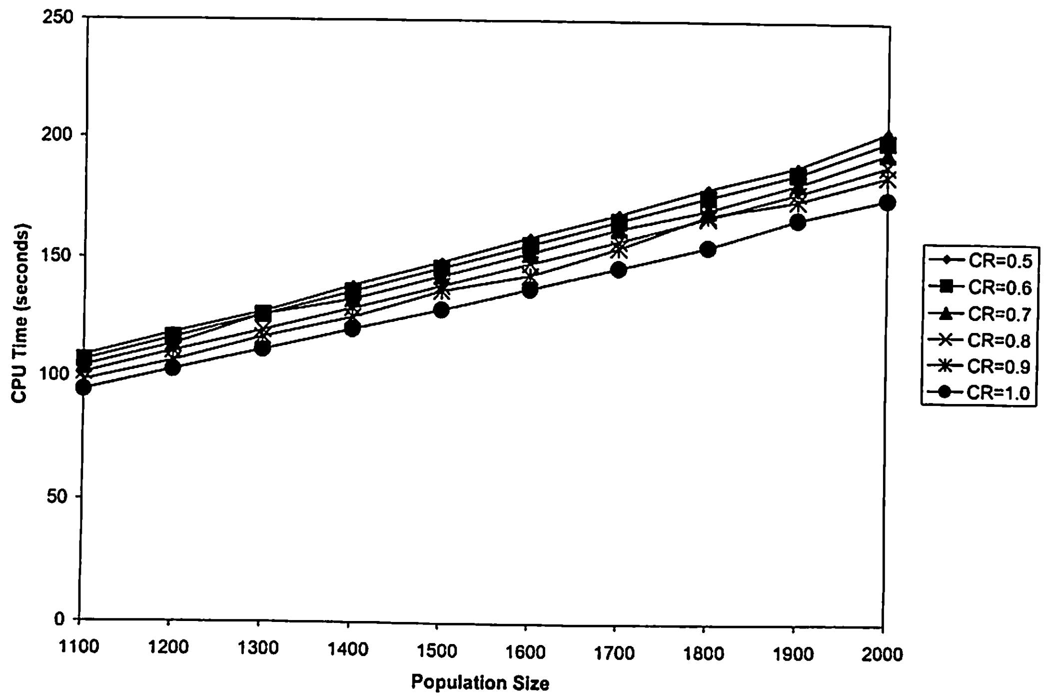

Fig. 6.44 CPU time variation for different crossover constant and population sizes (DE/best/1/bin, F=0.5)

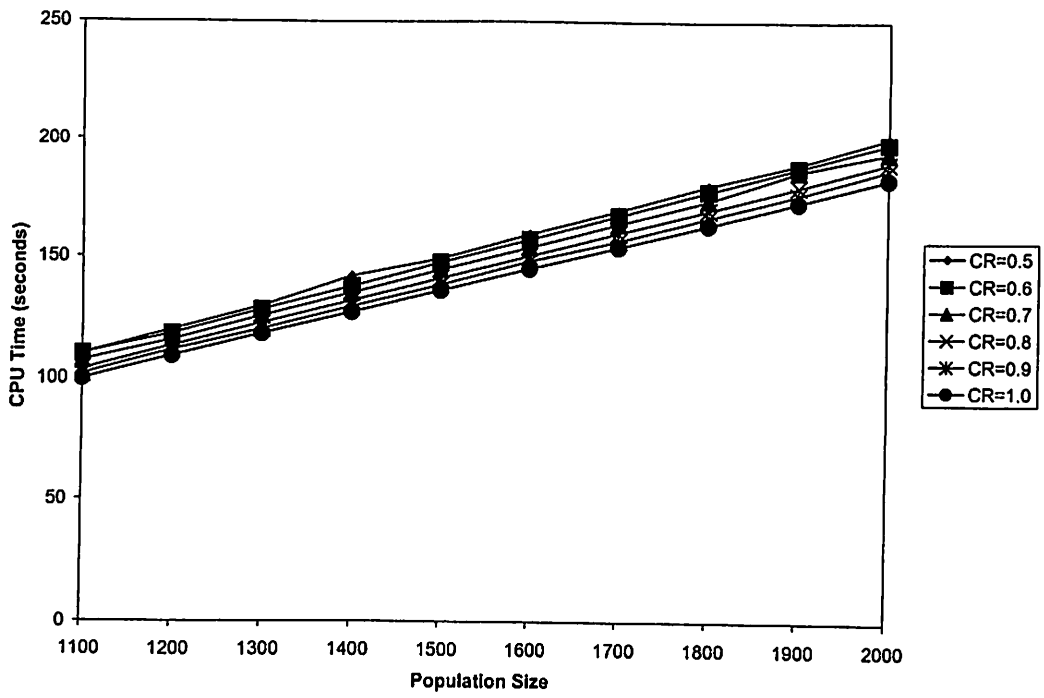

Fig. 6.45 CPU time variation for different crossover constant and population sizes (DE/best/2/bin, F=0.5)

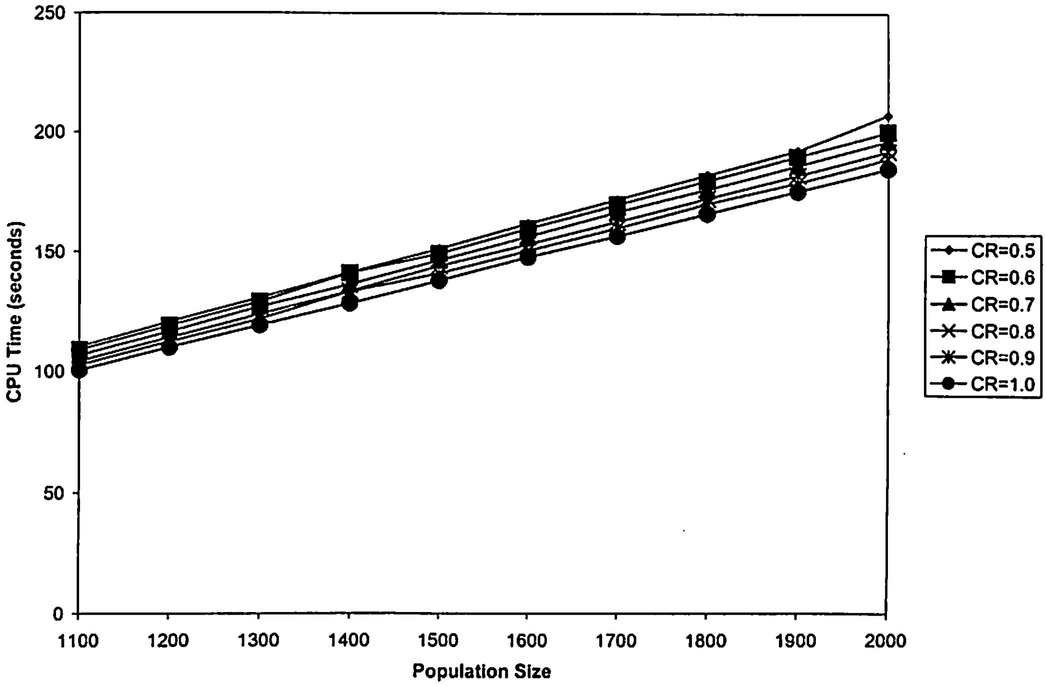

Fig. 6.46 CPU time variation for different crossover constant and population sizes (DE/rand/2/bin, F=0.5)

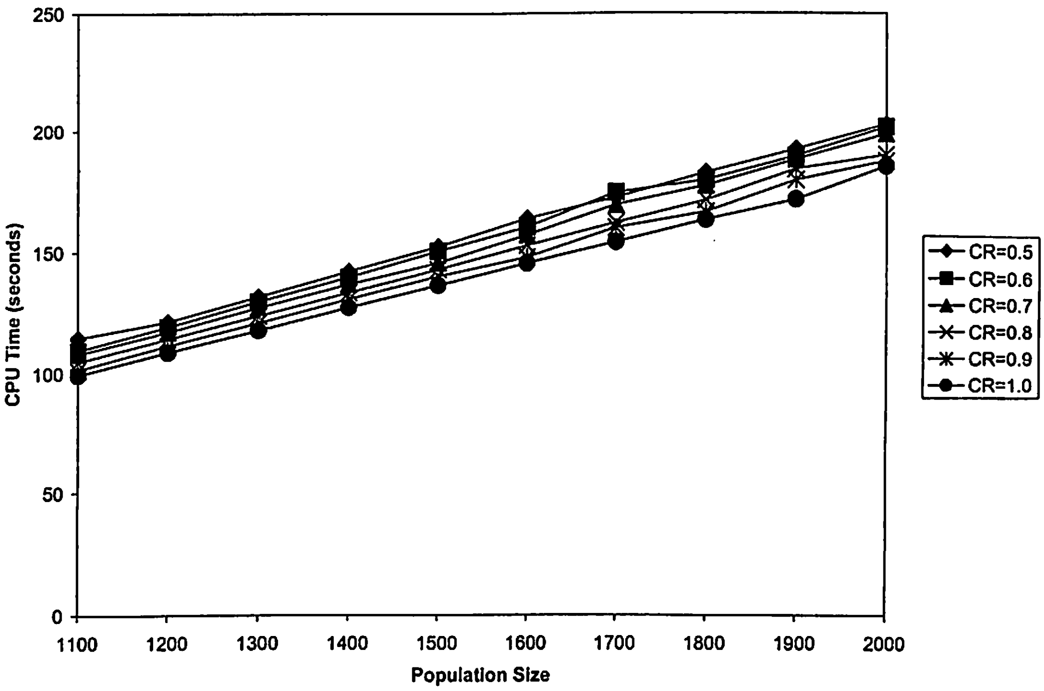

Fig. 6.47 CPU time variation for different crossover constant and population sizes (DE/rand-to-best/1/bin, F=0.5)

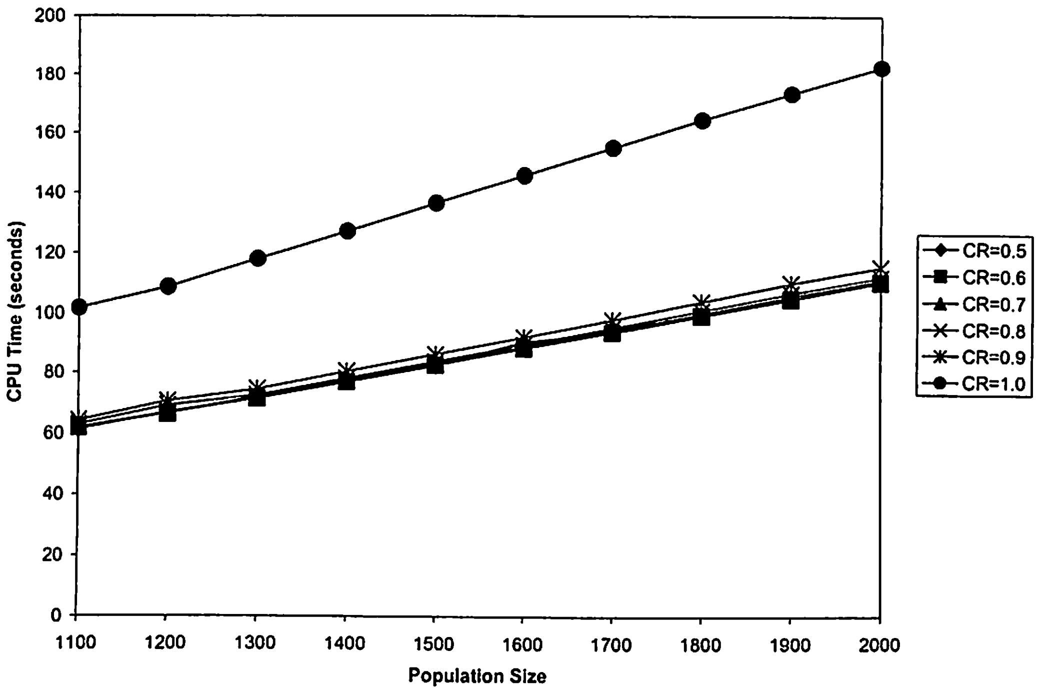

Fig. 6.48 CPU time variation for different crossover constant and population sizes (DE/rand/1/exp, F=0.5)

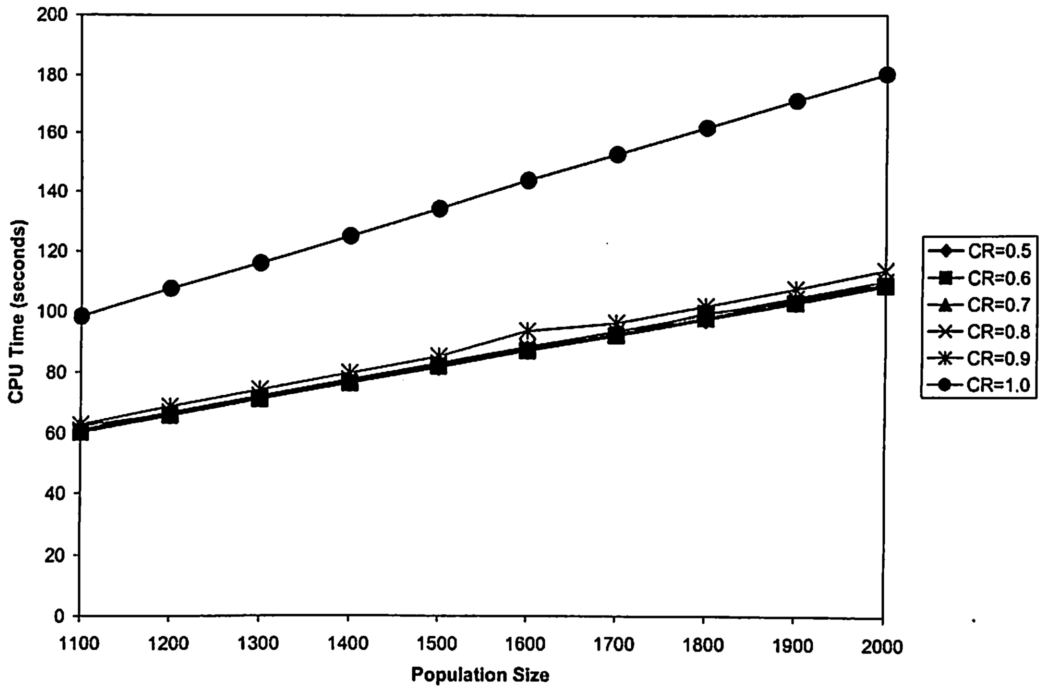

Fig. 6.49 CPU time variation for different crossover constant and population sizes (DE/best/1/exp, F=0.5)

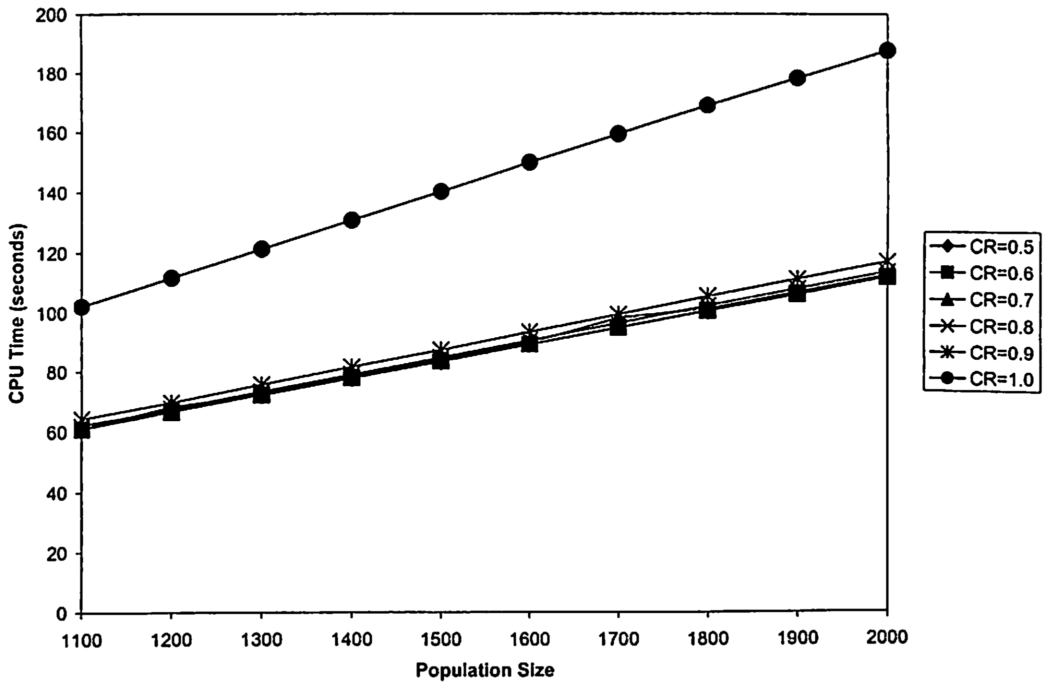

Fig. 6.50 CPU time variation for different crossover constant and population sizes (DE/best/2/exp, F=0.5)

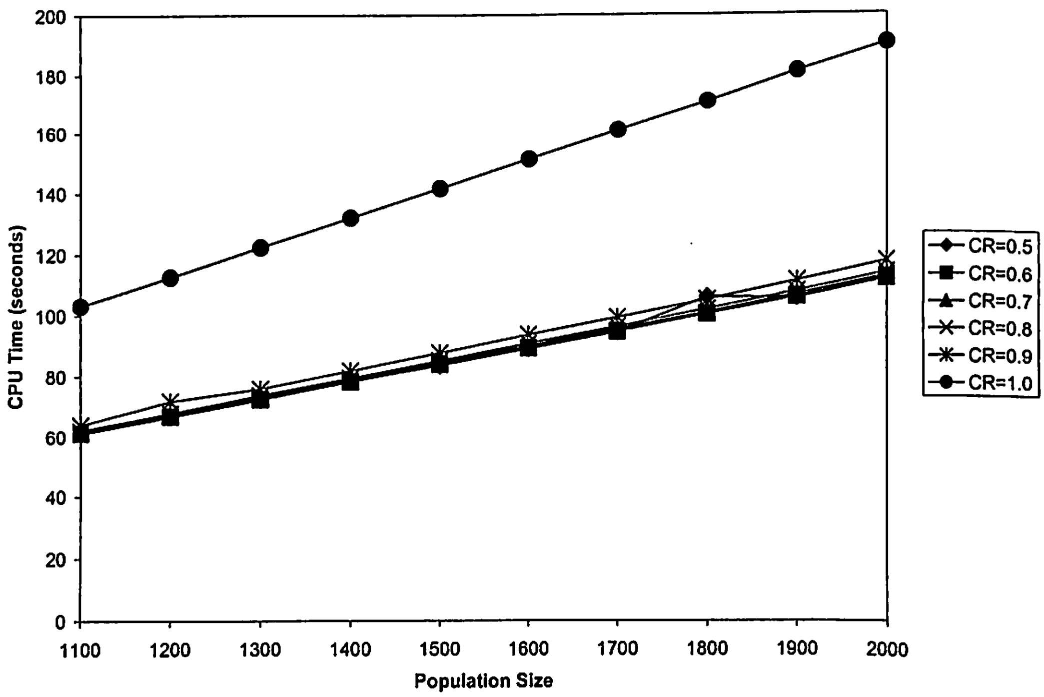

Fig. 6.51 CPU time variation for different crossover constant and population sizes (DE/rand/2/exp, F=0.5)

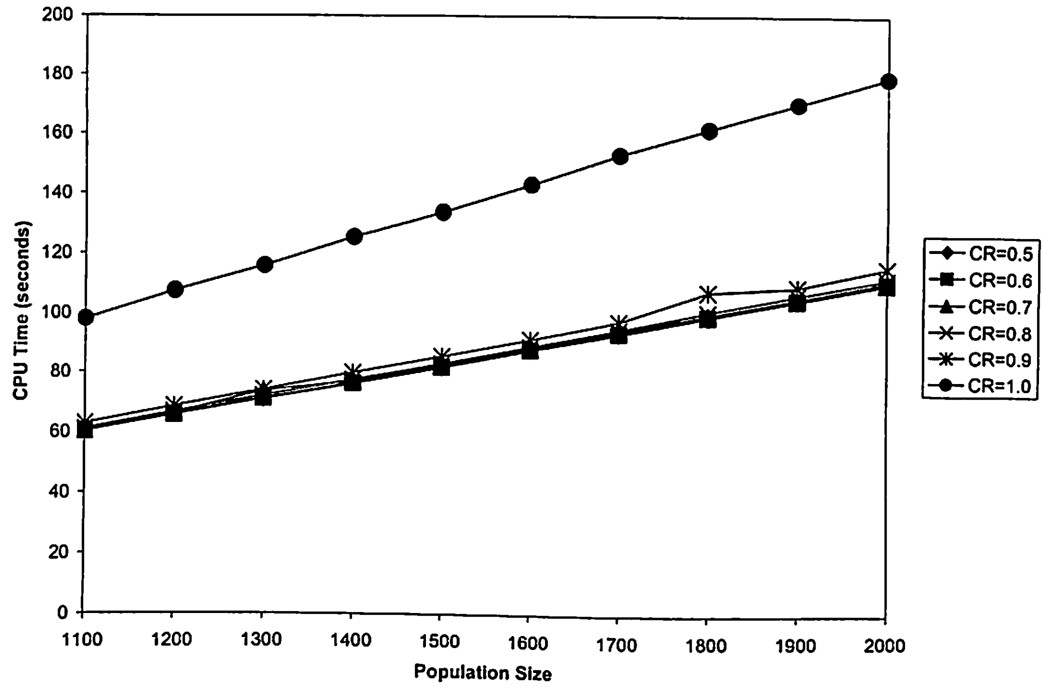

Fig. 6.52 CPU time variation for different crossover constant and population sizes (DE/rand-to-best/1/exp, F=0.5)

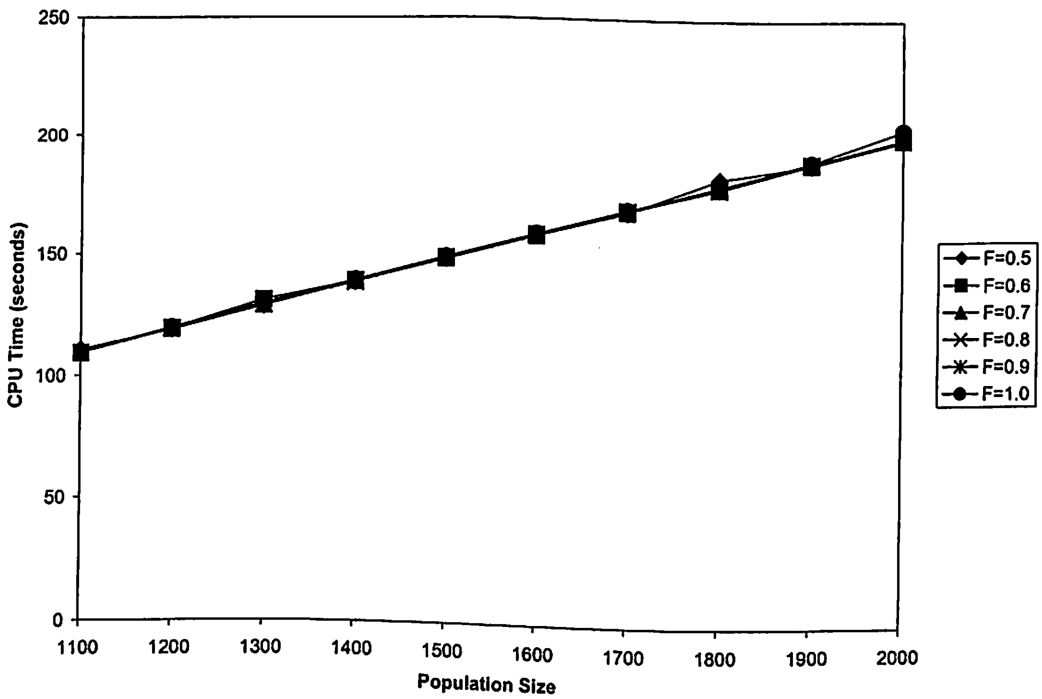

Fig. 6.53 CPU time variation for different weighting factor and population sizes (DE/rand/1/bin, CR=1.0)

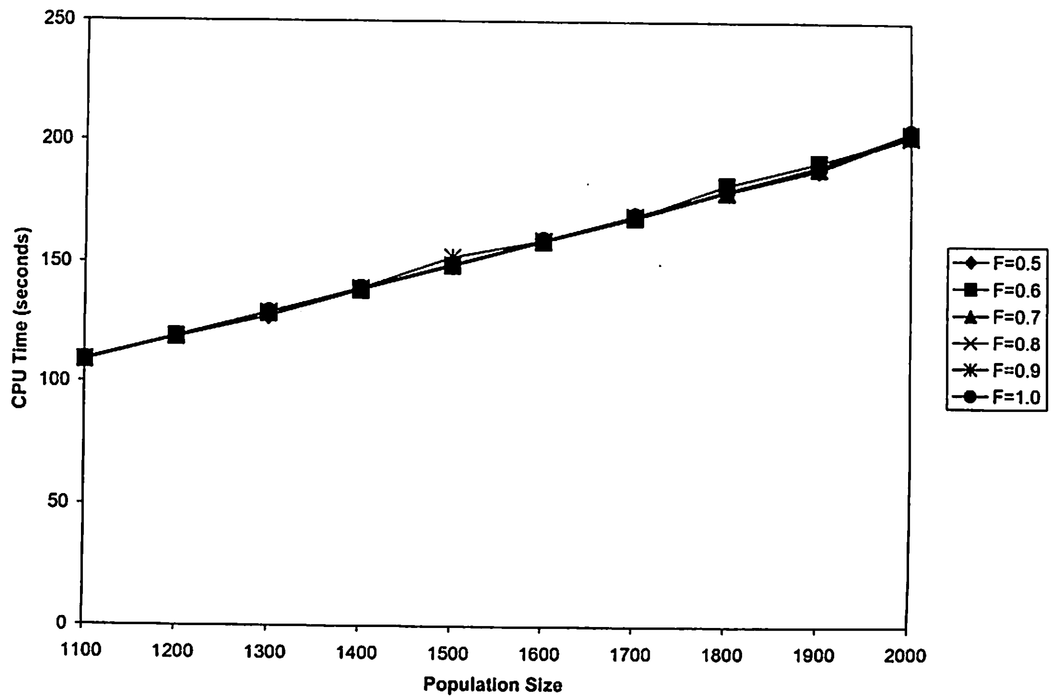

Fig. 6.54 CPU time variation for different weighting factor and population sizes (DE/best/1/bin, CR=1.0)

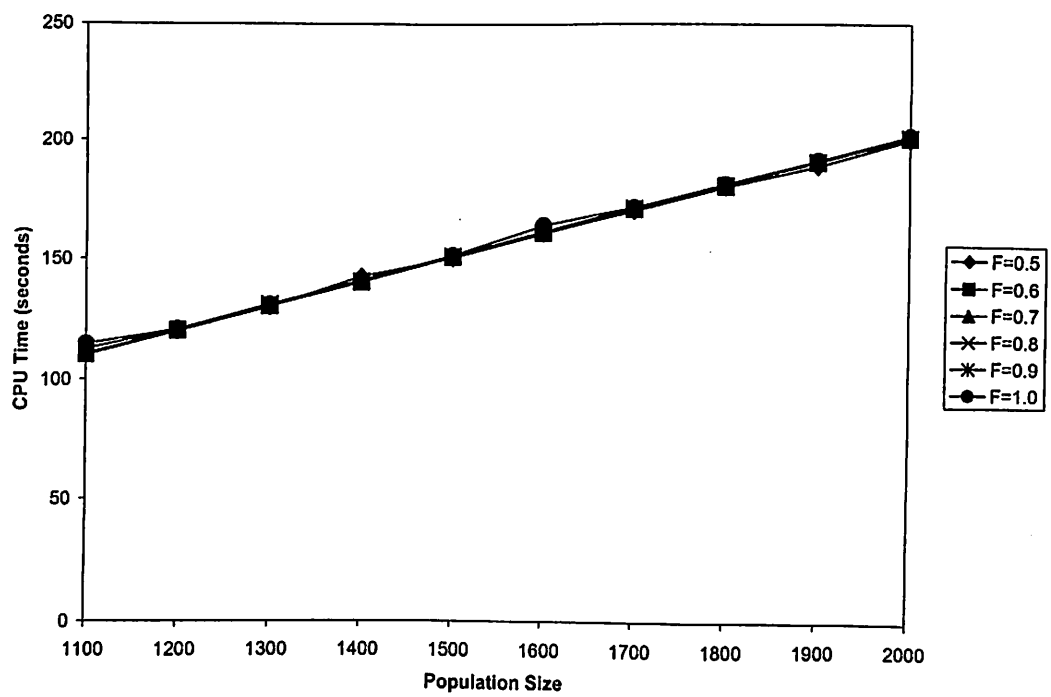

Fig. 6.55 CPU time variation for different weighting factor and population sizes (DE/best/2/bin, CR=1.0)

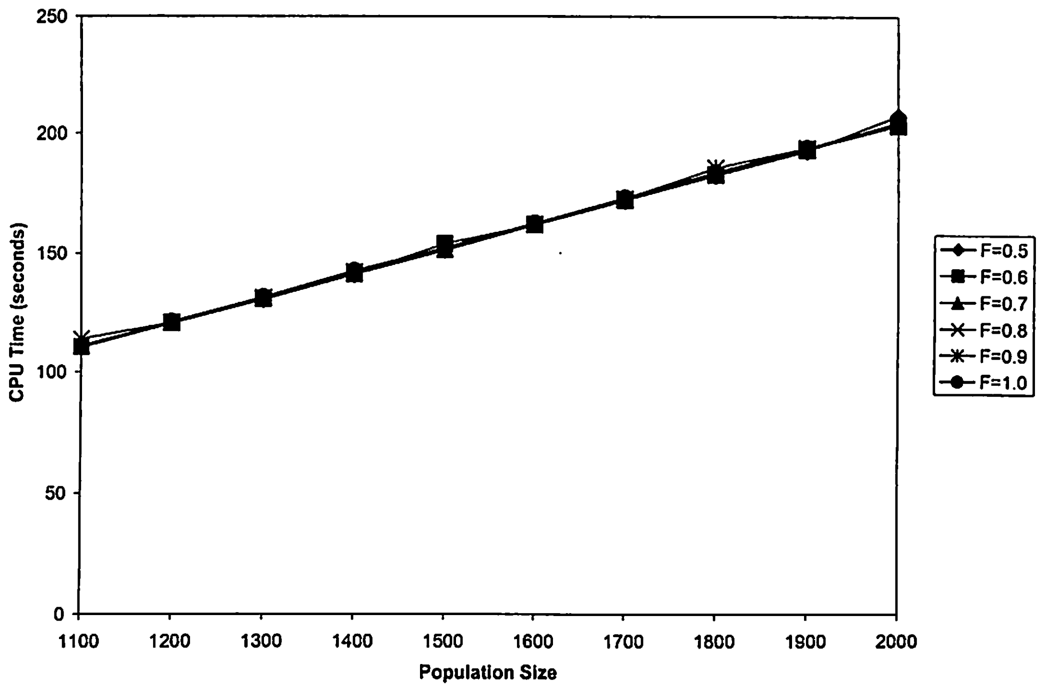

Fig. 6.56 CPU time variation for different weighting factor and population sizes (DE/rand/2/bin, CR=1.0)

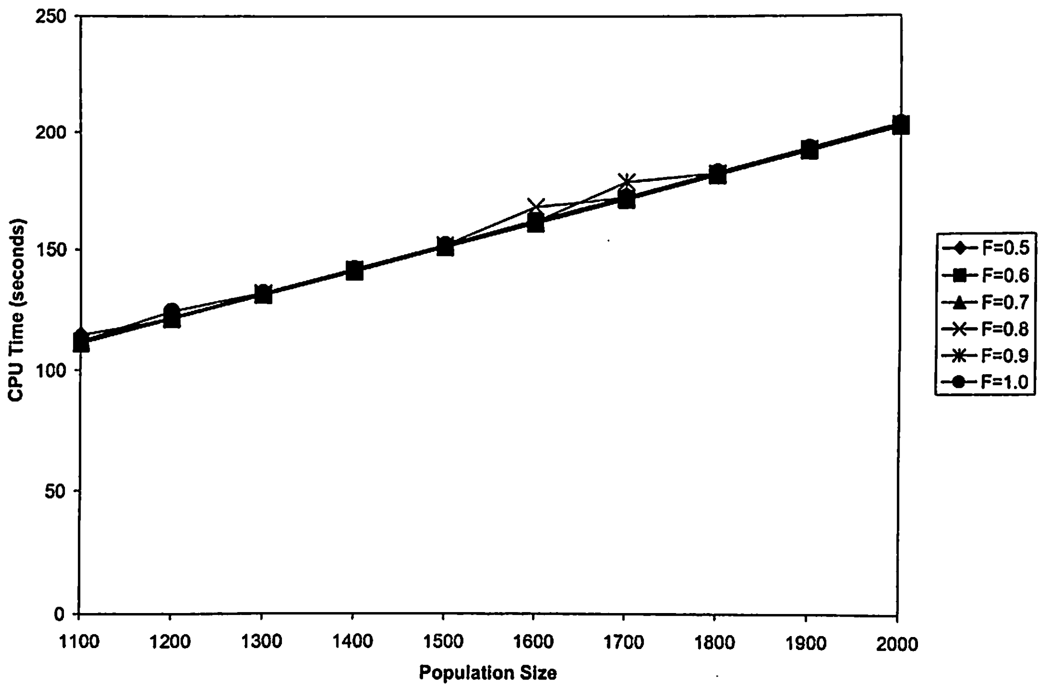

Fig. 6.57 CPU time variation for different weighting factor and population sizes (DE/rand-to-best/1/bin, CR=1.0)

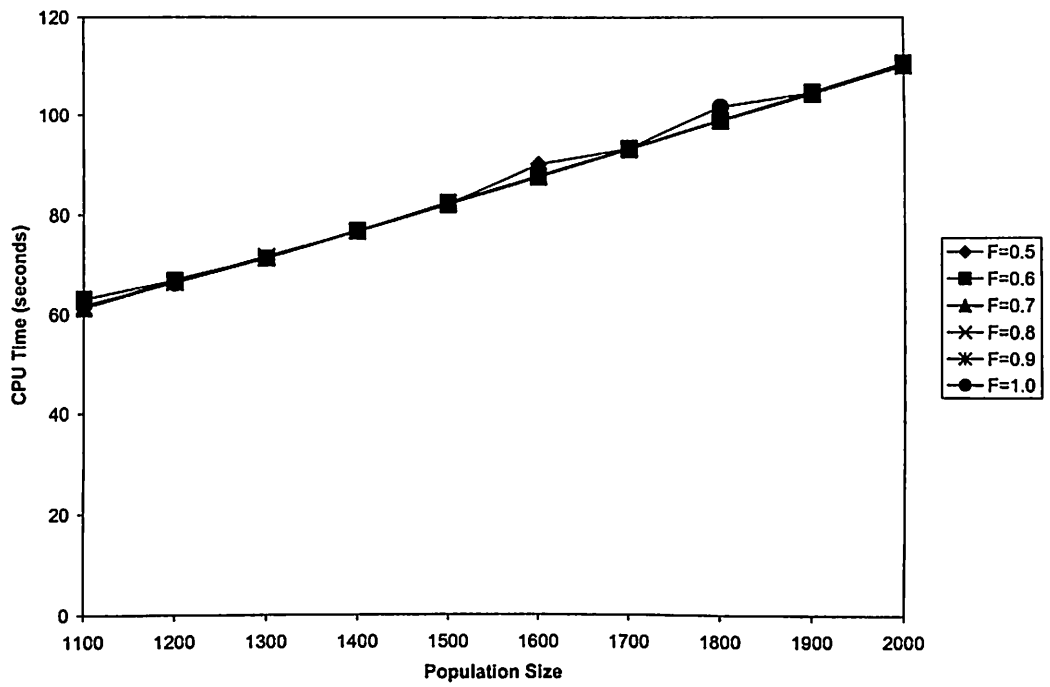

Fig. 6.58 CPU time variation for different weighting factor and population sizes (DE/rand/1/exp, CR=1.0)

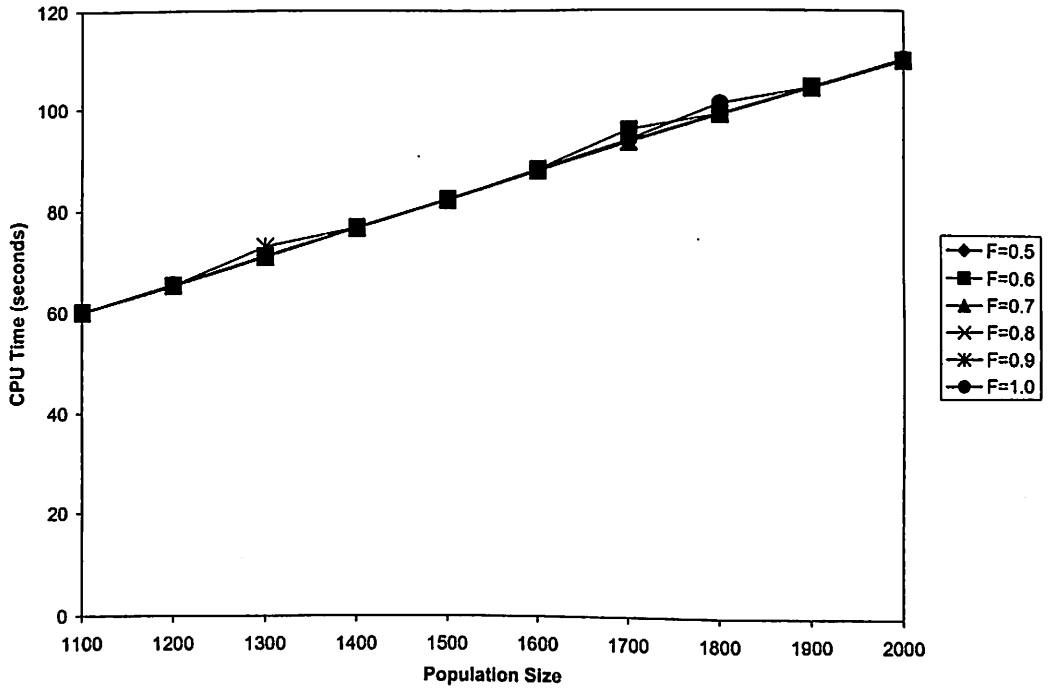

Fig. 6.59 CPU time variation for different weighting factor and population sizes (DE/best/1/exp, CR=1.0)

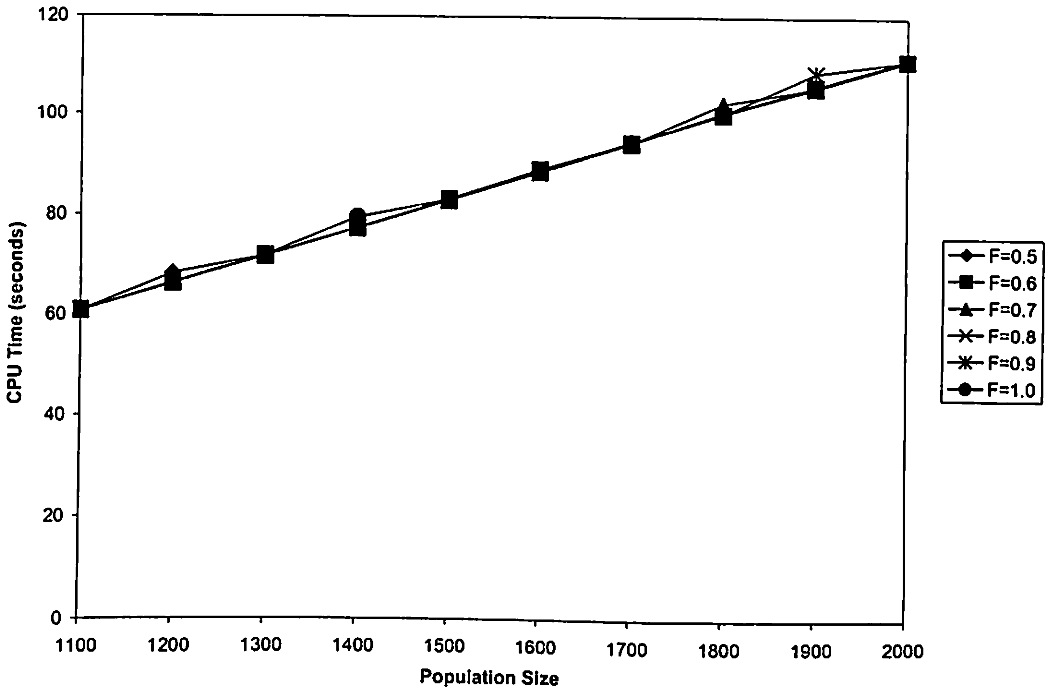

Fig. 6.60 CPU time variation for different weighting factor and population sizes (DE/best/2/exp, CR=1.0)

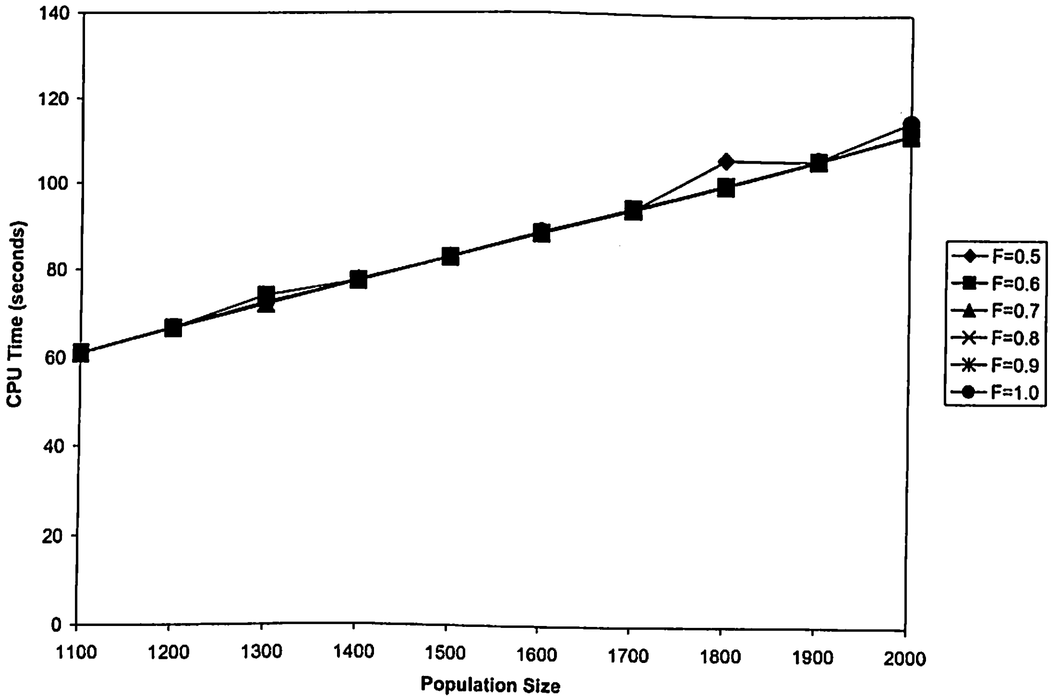

Fig. 6.61 CPU time variation for different weighting factor and population sizes (DE/rand/2/exp, CR=1.0)

- A similar trend is observed for DE/best/2/bin (Fig. 6.24) as compared to DE/rand/1/bin (Fig. 6.22). In this case, the net benefits are high for CR=1.0 and no specific trend is observed for benefits for other CR values.
- It is observed from Fig. 6.25 (DE/rand/2/bin) that no trend is observed with increase in population size and CR values.
- It is observed from Fig. 6.26 (DE/rand-to-best/1/bin) that the net benefits for CR=1.0 is lower (with an exception at NP=1500).
- It is observed from Fig. 6.27 (DE/rand/1/exp) that the net benefits increase for CR values 0.5 to 1.0 (except for slight variations beyond NP=1500).
- It is observed from Fig. 6.28 (DE/best/1/exp) that except for NP=1200, the net benefits are maximum for CR=0.9.
- It is observed from Fig. 6.29 (DE/best/2/exp) that the net benefits are maximum for CR=1.0 followed by CR=0.9 for all population sizes (except at NP=2000, in which case the net benefits are more at CR=0.8 as compared to CR=0.9). No specific trend is observed for other CR values and population sizes.
- It is observed from Fig. 6.30 (DE/rand/2/exp) that the net benefits are maximum for CR=0.9 for all population sizes. The net benefits vary from Rs.111.83 crores (for CR=0.5) to Rs.112.77 crores (for CR=0.8) for NP=1100. For NP=2000, net benefits vary from Rs.112.09 crores (for CR=0.5) to Rs.112.60 crores (for CR=0.8).
- It is observed from Fig. 6.31 (DE/rand-to-best/1/exp) that maximum net benefits are observed at CR=0.9.

Type II - Variation of net benefits for different population sizes (NP) and ten strategies for various weighting factor (F) values with a specific crossover rate (CR) value of 1.0

- It is observed from Fig. 6.32 (DE/rand/1/bin) that net benefits increase from Rs.111.21 crores to Rs.112.90 crores for F=1.0 to 0.5 at NP=1100. It is also observed that net benefits obtained with F=0.5 and 0.6 for all population sizes are significantly higher as compared to other F values.

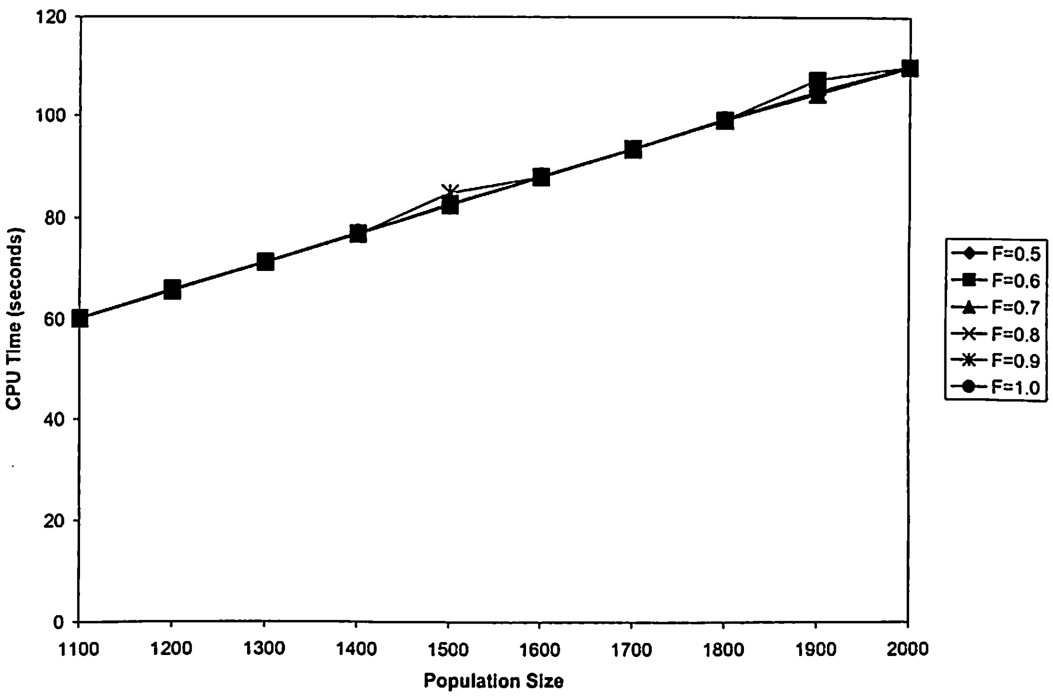

Fig. 6.62 CPU time variation for different weighting factor and population sizes (DE/rand-to-best/1/exp, CR=1.0)

Type I - Variation of net benefits for different population sizes (NP) and ten strategies for various crossover rate (CR) values with a specific weighting factor (F) value of 0.5

- It is observed from Fig. 6.22 (DE/rand/1/bin) that net benefits vary from population size 1100 (Rs.111.66 crores for CR=0.5, Rs.112.90 crores for CR=1.0) to 2000 (Rs.111.84 crores for CR=0.8, Rs.112.95 crores for CR=1.0). At population size 1100, they increase with an increase of crossover rate from 0.5 to 1.0. Moreover, this trend is not observed at population size 2000. It is also observed that for all population sizes, crossover rates 0.9 and 1.0 maintain their separate identity.
- In case of strategy DE/best/1/bin (Fig. 6.23), no specific pattern is observed for the net benefits with reference to CR values except for CR=1.0. In case of CR=1.0, the net benefits are the lowest for all population sizes as compared with other CR values (except for NP=1200 and 1600 for CR=0.9). This is contrary to strategy (DE/rand/1/bin) where CR=1.0 provides maximum net benefits.

- A similar trend is observed for DE/best/2/bin (Fig. 6.24) as compared to DE/rand/1/bin (Fig. 6.22). In this case, the net benefits are high for CR=1.0 and no specific trend is observed for benefits for other CR values.
- It is observed from Fig. 6.25 (DE/rand/2/bin) that no trend is observed with increase in population size and CR values.
- It is observed from Fig. 6.26 (DE/rand-to-best/1/bin) that the net benefits for CR=1.0 is lower (with an exception at NP=1500).
- It is observed from Fig. 6.27 (DE/rand/1/exp) that the net benefits increase for CR values 0.5 to 1.0 (except for slight variations beyond NP=1500).
- It is observed from Fig. 6.28 (DE/best/1/exp) that except for NP=1200, the net benefits are maximum for CR=0.9.
- It is observed from Fig. 6.29 (DE/best/2/exp) that the net benefits are maximum for CR=1.0 followed by CR=0.9 for all population sizes (except at NP=2000, in which case the net benefits are more at CR=0.8 as compared to CR=0.9). No specific trend is observed for other CR values and population sizes.
- It is observed from Fig. 6.30 (DE/rand/2/exp) that the net benefits are maximum for CR=0.9 for all population sizes. The net benefits vary from Rs.111.83 crores (for CR=0.5) to Rs.112.77 crores (for CR=0.8) for NP=1100. For NP=2000, net benefits vary from Rs.112.09 crores (for CR=0.5) to Rs.112.60 crores (for CR=0.8).
- It is observed from Fig. 6.31 (DE/rand-to-best/1/exp) that maximum net benefits are observed at CR=0.9.

Type II - Variation of net benefits for different population sizes (NP) and ten strategies for various weighting factor (F) values with a specific crossover rate (CR) value of 1.0

- It is observed from Fig. 6.32 (DE/rand/1/bin) that net benefits increase from Rs.111.21 crores to Rs.112.90 crores for F=1.0 to 0.5 at NP=1100. It is also observed that net benefits obtained with F=0.5 and 0.6 for all population sizes are significantly higher as compared to other F values.

- It is observed from Fig. 6.33 (DE/best/1/bin) that low value of net benefits are observed for F=0.5 for all population sizes except for NP=1500.
- It is observed from Fig. 6.34 (DE/best/2/bin) that the net benefits are maximum for F=0.5. For other F values, no specific trend is observed.
- In case of Fig. 6.35 (DE/rand/2/bin), no specific trend of net benefits is observed.
- It is observed from Fig. 6.36 (DE/rand-to-best/1/bin) that the net benefits are minimum for F=0.5 for all population sizes followed by F=1.0 (with an exception at NP=2000).
- It is observed from Fig. 6.37 (DE/rand/1/exp) that maximum net benefits are observed at F=0.5 followed by F=0.6. At population size 1400, the net benefits converge (in decreasing order) to a value of Rs.112.72 crores for F=0.5 and 0.6.
- Similar trend is observed from Fig. 6.38 (DE/best/1/exp) that net benefits are maximum at F=0.7 (except at NP=1500). No specific trend is observed with reference to other F values.
- It is observed from Fig. 6.39 (DE/best/2/exp) that the net benefits decrease from F=0.5 to F=0.6 and no specific trend is observed for other F values.
- A similar trend is observed from Fig. 6.40 (DE/rand/2/exp) where the net benefits are the maximum at F=0.5. No specific trend is observed for other F values.
- It is observed from Fig. 6.41 (DE/rand-to-best/1/exp) that the net benefits are minimum for F=0.5 followed by F=1.0 (increasing order) which is similar to that of Fig. 6.36 (DE/rand-to-best/1/bin). No specific trend is observed for other F values and population sizes.

Type III - Variation of net benefits for ten DE strategies for various combinations of population size (NP), crossover rate (CR) and weighting factor (F) obtained as optimal set of parameters for each strategy (with reference to Table 6.15)

- A narrow range of net benefits are observed from Fig. 6.42 for DE/rand/1/bin (Rs.111.79 crores, Rs.112.95 crores), DE/rand/2/bin (Rs.111.46 crores, Rs.112.32 crores) and DE/rand/1/exp (Rs.112.24 crores, Rs.113.10 crores).
- It is observed from Fig. 6.42 that a wide range of net benefits are observed for DE/best/1/bin (Rs.111.15 crores, Rs.113.15 crores), DE/best/2/bin (Rs.111.53

crores, Rs.113.15 crores), DE/rand-to-best/1/bin (Rs.111.14 crores, Rs.113.15 crores), DE/best/1/exp (Rs.111.17 crores, Rs.113.15 crores), DE/best/2/exp (Rs.111.22 crores, Rs.112.97 crores), DE/rand/2/exp (Rs.111.42 crores, Rs.112.78 crores) and DE/rand-to-best/1/exp (Rs.111.23 crores, Rs.113.15 crores).

- The range of net benefits is less in case of DE/rand-to-best/1/exp (Rs.1.92 crores) as compared to DE/rand-to-best/1/bin (Rs.2.00 crores).

Type IV - CPU time variation for different population sizes and ten strategies for various crossover rate values with a specific weighting factor value of 0.5

- It is observed from Fig. 6.43 (DE/rand/1/bin), Fig. 6.44 (DE/best/1/bin), Fig. 6.45 (DE/best/2/bin), Fig. 6.46 (DE/rand/2/bin), Fig. 6.47 (DE/rand-to-best/1/bin) that CPU time increases with increase in population size. It is also observed that CPU time increases with decrease in CR value (from 1.0 to 0.5) for any given population size. These similarities in CPU time increments may be due to the similar nature of the crossover i.e., binomial crossover.
- It is observed from Fig. 6.48 (DE/rand/1/exp), Fig. 6.49 (DE/best/1/exp), Fig. 6.50 (DE/best/2/exp), Fig. 6.51 (DE/rand/2/exp), Fig. 6.52 (DE/rand-to-best/1/exp) that CPU time increases with increase in population size. CPU time is more for CR=1.0 as compared to other CR values (0.5 to 0.9) for all population sizes. It is also observed that CPU time is almost same for all other CR values other than CR=1.0 for a given population size.
- The distinct nature of binomial and exponential crossover is clearly visible from the above two sets of graphs i.e., Fig. 6.43 (DE/rand/1/bin) to Fig. 6.47 (DE/rand-to-best/1/bin) and Fig. 6.48 (DE/rand/1/exp) to Fig. 6.52 (DE/rand-to-best/1/exp). It is also observed that CPU time is less in case of exponential crossover as compared to binomial crossover. In case of binomial crossover, the minimum and maximum CPU time is 94.22 seconds and 207.45 seconds whereas in case of exponential crossover, the CPU time is more only in case of CR=1.0 (190.27 seconds) whereas for all other CR values these are in the range of 60.02 seconds to 112.23 seconds.

- For CR=1.0, CPU time requirement is less for binomial crossover and more for exponential crossover. With CR=1.0, any search direction in the search space is equally likely and moreover it gives faster convergence if convergence occurs. In this problem, CR=1.0 may have given faster convergence using binomial crossover which takes less CPU time whereas no convergence would have occurred in case of exponential crossover thereby taking more CPU time (Onwubolu and Babu, 2004).

Type V - CPU time variation for different population sizes and ten strategies for various weighting factor values with a specific crossover rate value of 1.0

- It is observed from Fig. 6.53 (DE/rand/1/bin), Fig. 6.54 (DE/best/1/bin), Fig. 6.55 (DE/best/2/bin), Fig. 6.56 (DE/rand/2/bin), Fig. 6.57 (DE/rand-to-best/1/bin) which represent binomial crossover that CPU time is in the range of 108.63 seconds for NP=1100 and 207.45 seconds for NP=2000. In case of exponential crossover (i.e., Fig. 6.58 (DE/rand/1/exp), Fig. 6.59 (DE/best/1/exp), Fig. 6.60 (DE/best/2/exp), Fig. 6.61 (DE/rand/2/exp), Fig. 6.62 (DE/rand-to-best/1/exp)) these values are almost half of the former (i.e., in the range of 60.02 seconds for NP=1100 and 115.09 seconds for NP=2000).

Inferences:

- Maximum net benefits are observed for high values of crossover constant (CR) and low values of weighting factor (F) for any population size (NP) and strategy.
- No specific trend of net benefits is observed with increase in NP, CR and F values for any strategy.
- CPU time requirement increases with increase in population size and decrease in CR value (from 1.0 to 0.5) for any population size and strategy.
- CPU time requirement for DE strategies with exponential crossover (DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp) shows similar values for any CR value (other than CR=1.0) and for a given population size.

- It is observed that CPU time requirement is less in case of exponential crossover strategies (DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp) as compared to binomial crossover strategies (DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin).
- For CR=1.0, CPU time requirement is less for binomial crossover and more for exponential crossover.

6.3.3.3 Simulated Annealing (SA)

The parameters used for the study are number of iterations (NI) varying from 50 to 150 with an increment of 10 (11 levels), initial temperature (T) from 100 to 1000 with an increment of 100 (11 levels) and cooling rate (CoR) from 0.70 to 0.95 with an increment 0.05 i.e., 6 levels (Ingber, 1993; Deb, 1995; Rao, 2003). The final temperature and the accuracy to be achieved between the successive iterations are fixed as 0.1 and 10^{-5}. The resulting total number of combinations is $11 \times 11 \times 6 = 726$.

The program is run for 726 combinations to determine the optimal set of parameters as explained in Section 6.3.3.1. From sensitivity analysis, the optimal set is found as NI=130, T=600 and CoR=0.90 which yield net benefits of Rs.113.15 crores taking CPU time of 685.38 seconds which is based on PC with Pentium IV 2.4GHz/256MB RAM/40GB HDD. Effect of variation of each parameter is shown in the form of graphs from Fig. 6.63 to 6.82. The graphs are classified into three types and they are:

- Type I - Fig. 6.63 to Fig. 6.68 - Presents the variation of net benefits for different initial temperature (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000) and number of iterations (50, 70, 90, 110, 130, 150) for various cooling rates (0.70, 0.75, 0.80, 0.85, 0.90, 0.95).
- Type II - Fig. 6.69 to Fig. 6.79 presents the variation of net benefits for different initial temperature (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000) and cooling rates (0.70, 0.85, 0.95) for the number of iterations (50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150).

- Type III - Fig. 6.80 to Fig. 6.82 presents the CPU time variation for different initial temperature (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000) and number of iterations (50, 70, 90, 110, 130, 150) for various cooling rates (0.70, 0.85, 0.95). The graphs for cooling rate of 0.75, 0.80 and 0.90 are not presented due to their similar nature.

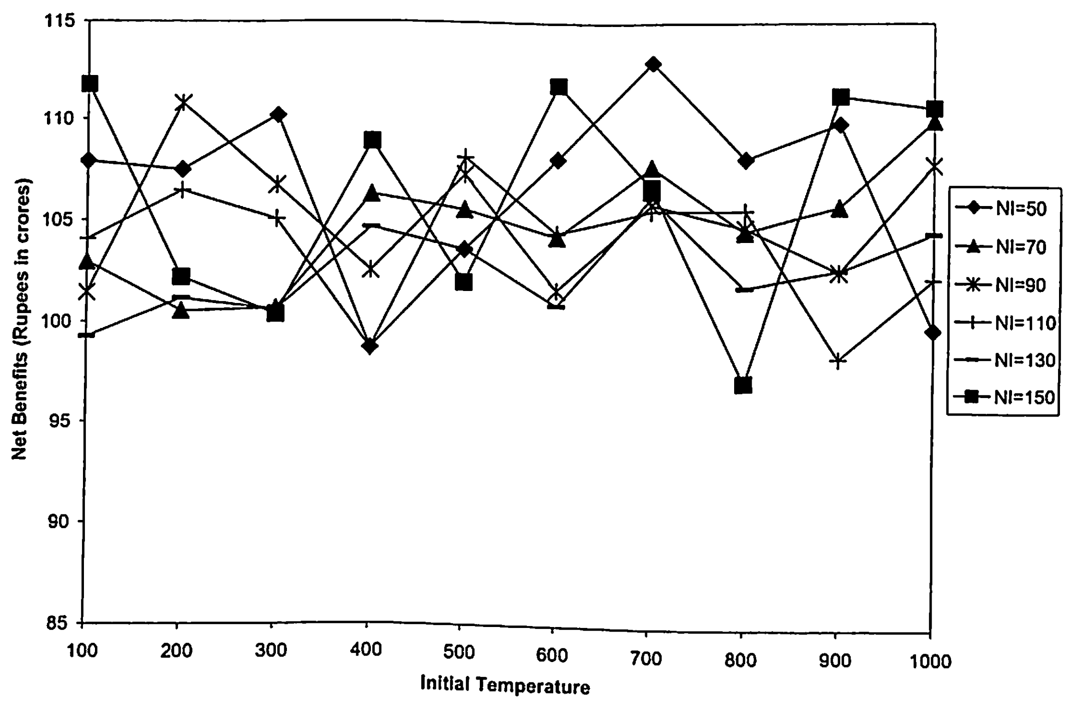

Fig. 6.63 Variation of net benefits for different number of iterations and initial temperature (CoR=0.70)

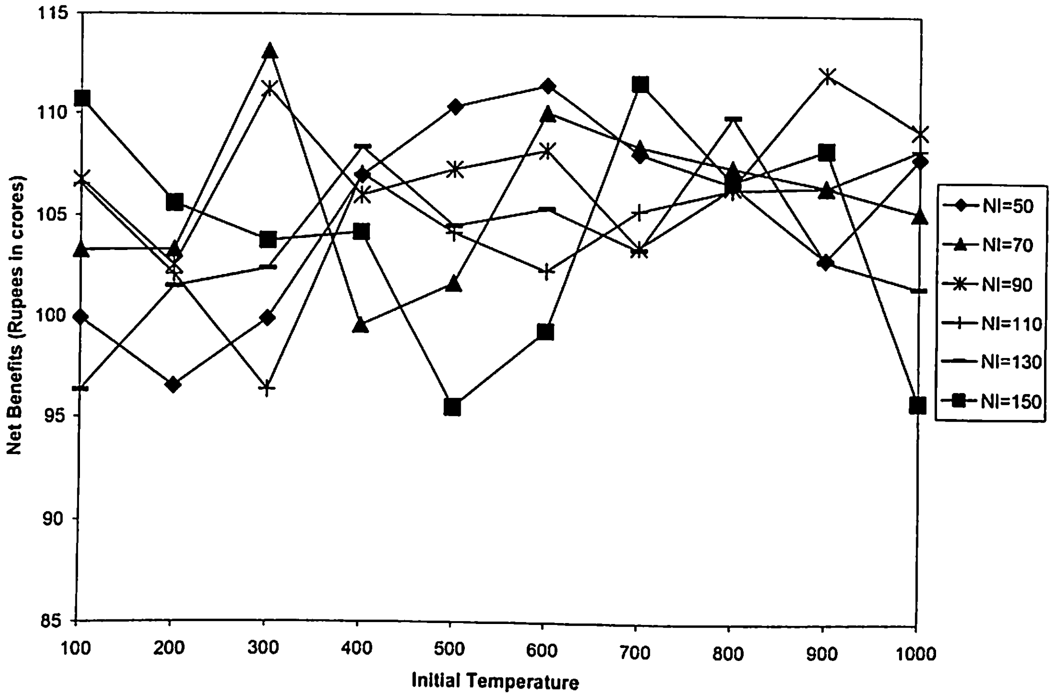

Fig. 6.64 Variation of net benefits for different number of iterations and initial temperature (CoR=0.75)

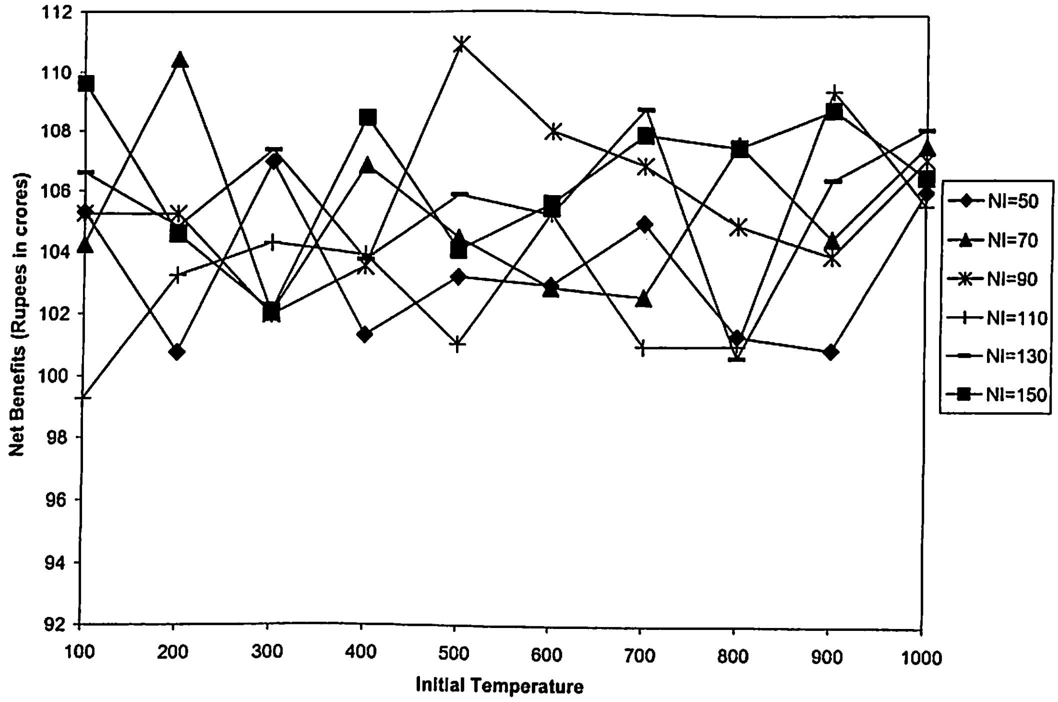

Fig. 6.65 Variation of net benefits for different number of iterations and initial temperature (CoR=0.80)

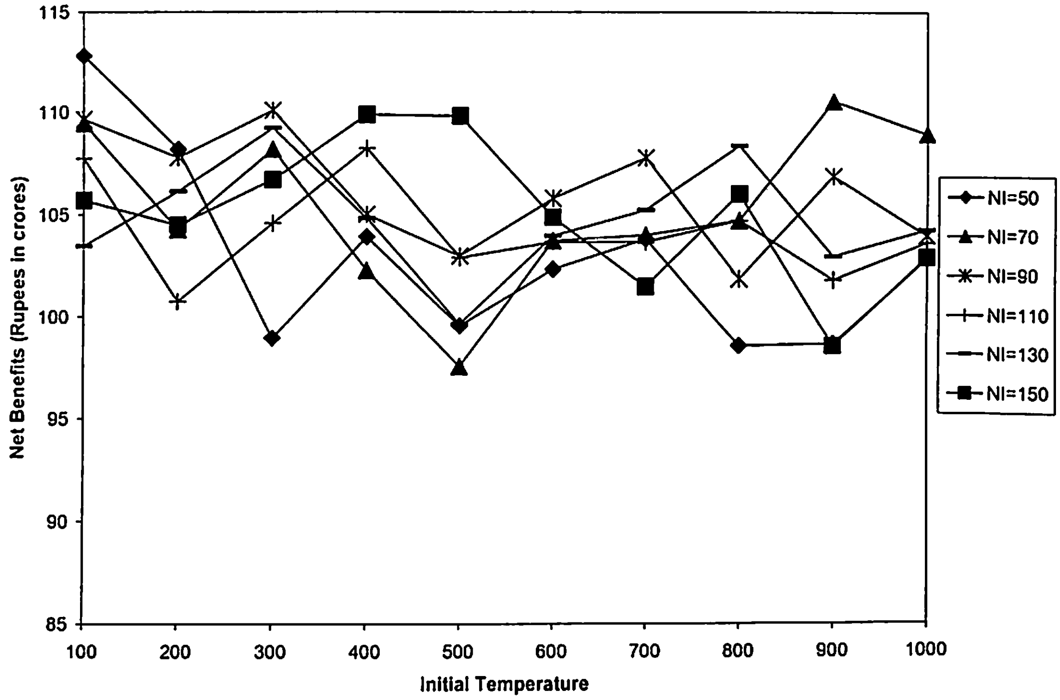

Fig. 6.66 Variation of net benefits for different number of iterations and initial temperature (CoR=0.85)

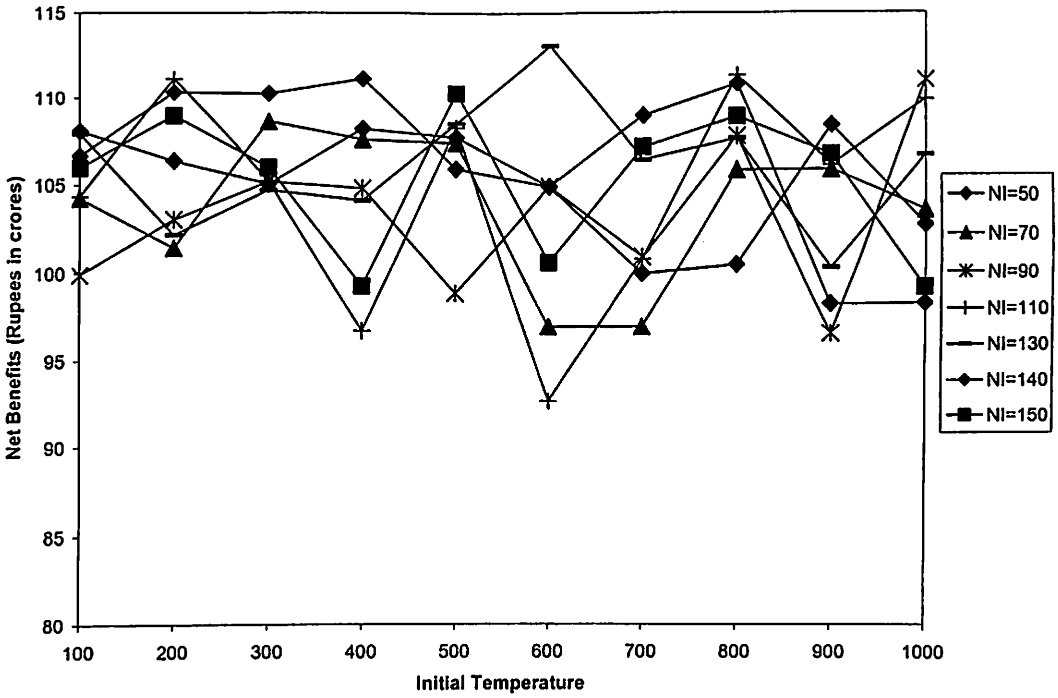

Fig. 6.67 Variation of net benefits for different number of iterations and initial temperature (CoR=0.90)

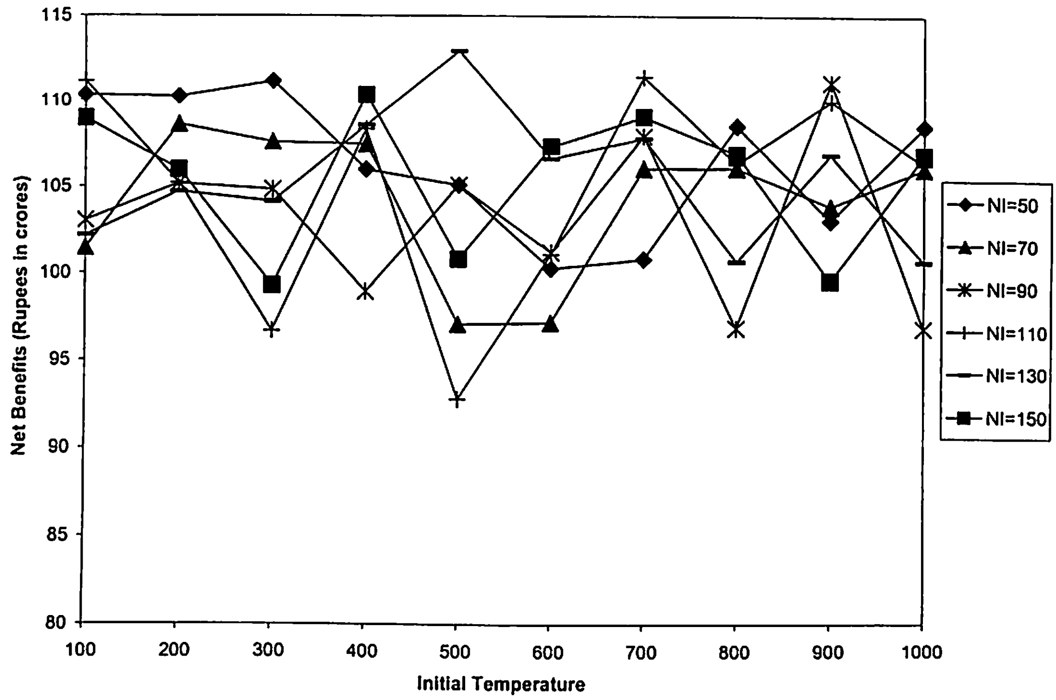

Fig. 6.68 Variation of net benefits for different number of iterations and initial temperature (CoR=0.95)

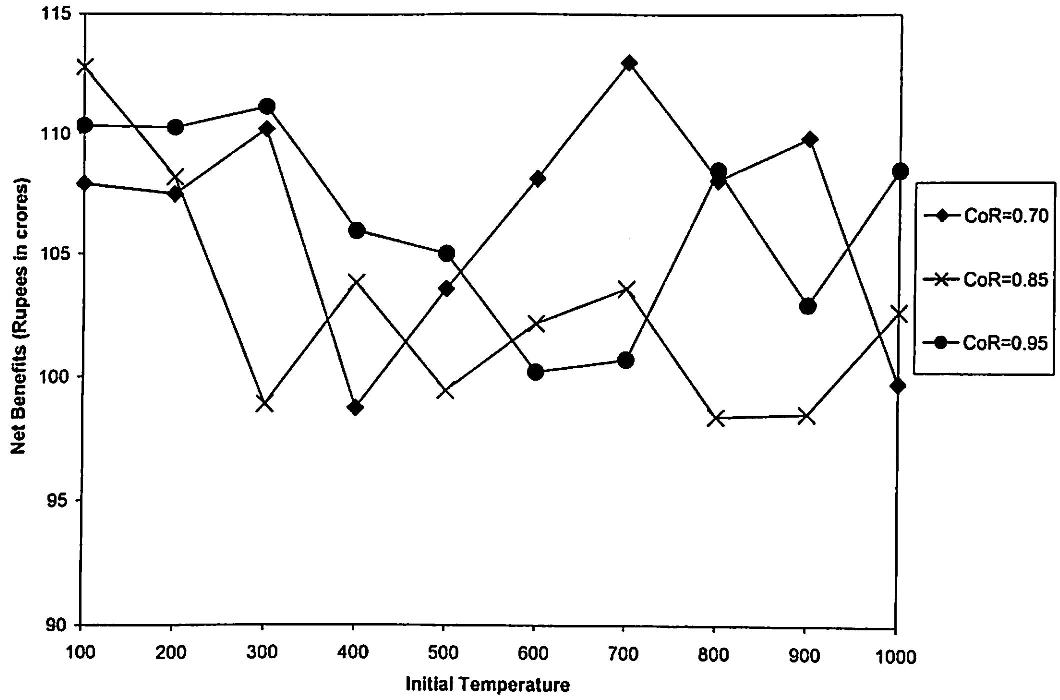

Fig. 6.69 Variation of net benefits for different cooling rates and initial temperature (NI=50)

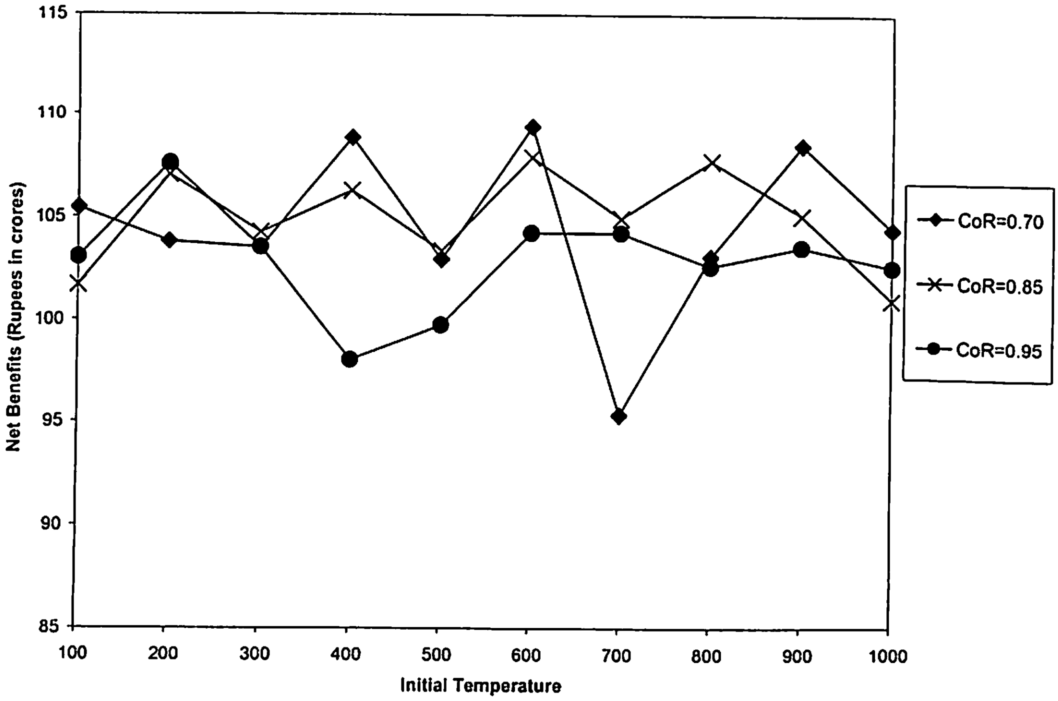

Fig. 6.70 Variation of net benefits for different cooling rates and initial temperature (NI=60)

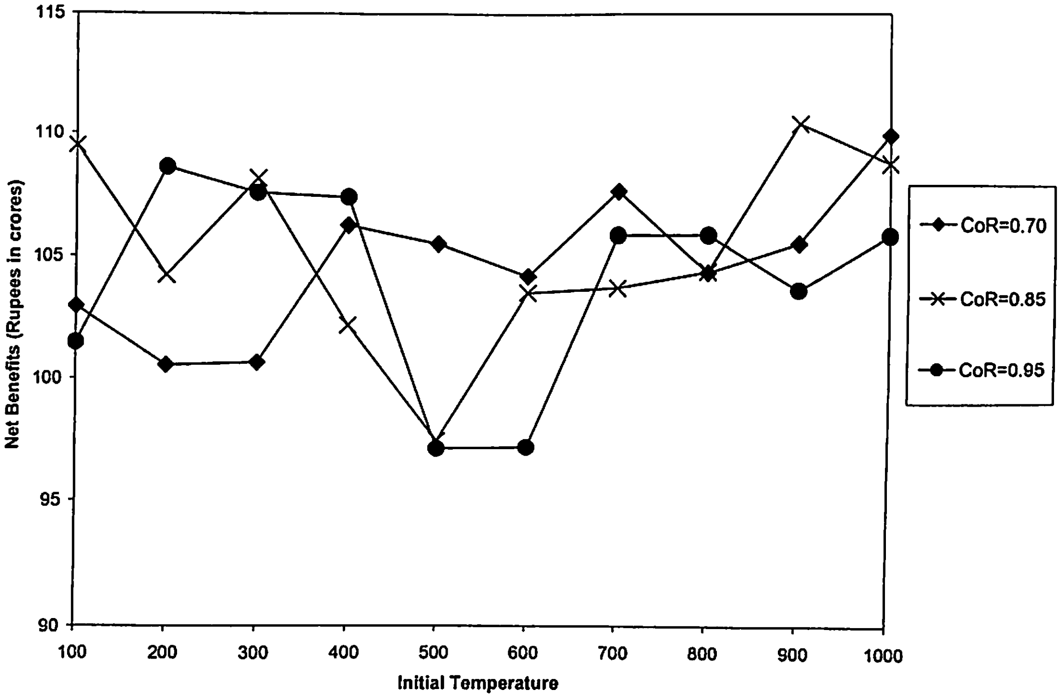

Fig. 6.71 Variation of net benefits for different cooling rates and initial temperature (NI=70)

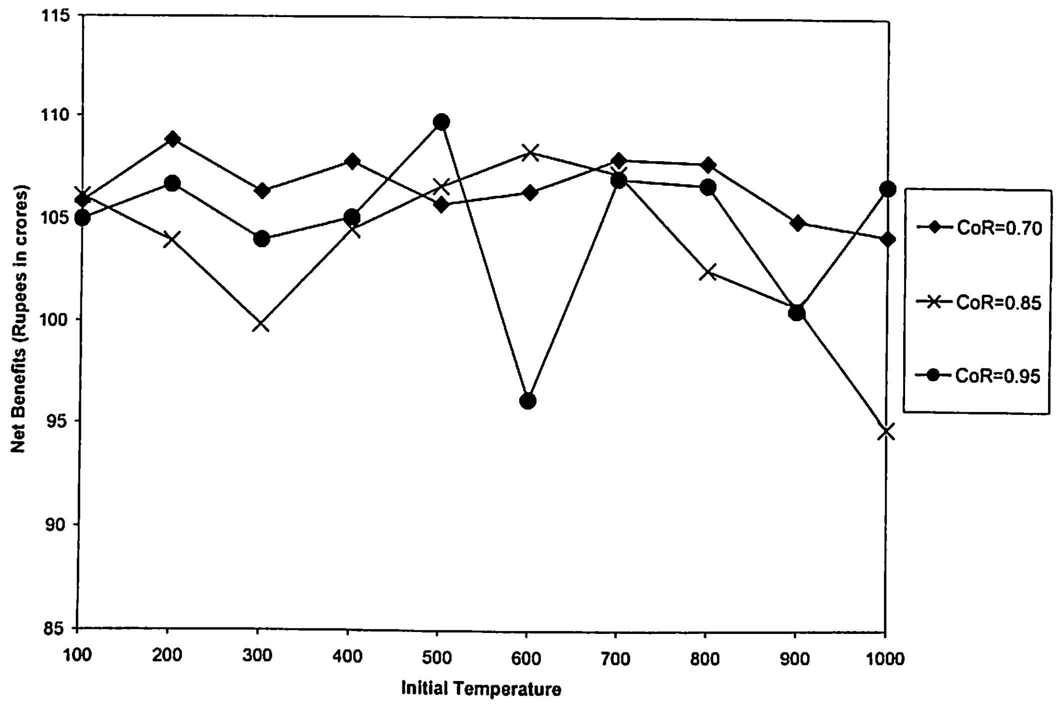

Fig. 6.72 Variation of net benefits for different cooling rates and initial temperature (NI=80)

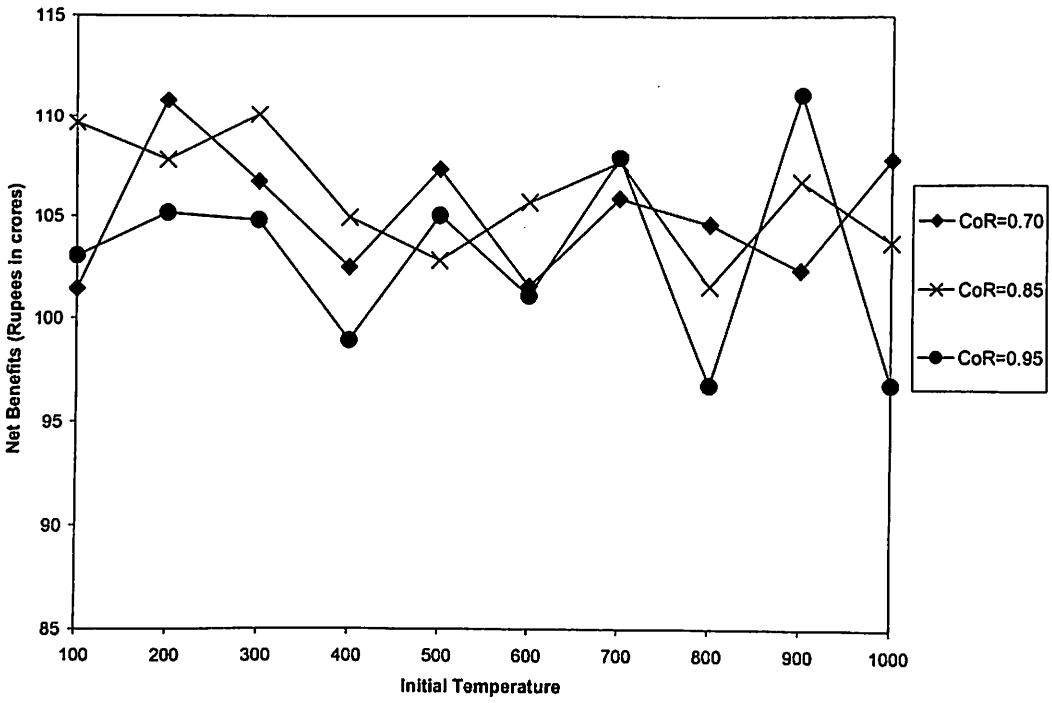

Fig. 6.73 Variation of net benefits for different cooling rates and initial temperature (NI=90)

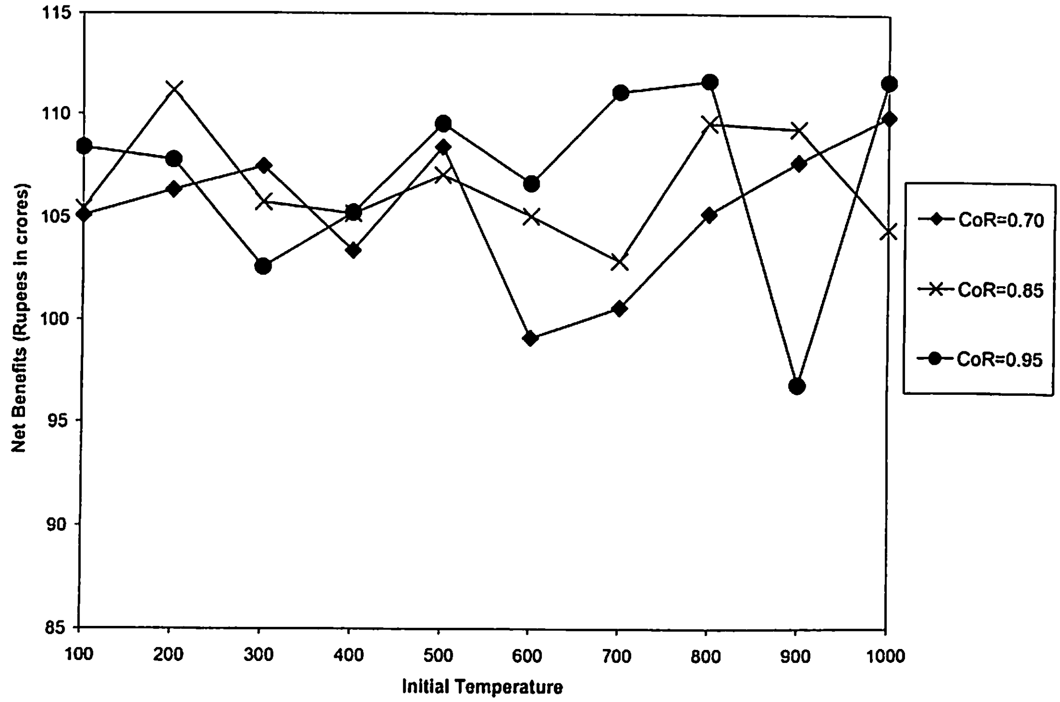

Fig. 6.74 Variation of net benefits for different cooling rates and initial temperature (NI=100)

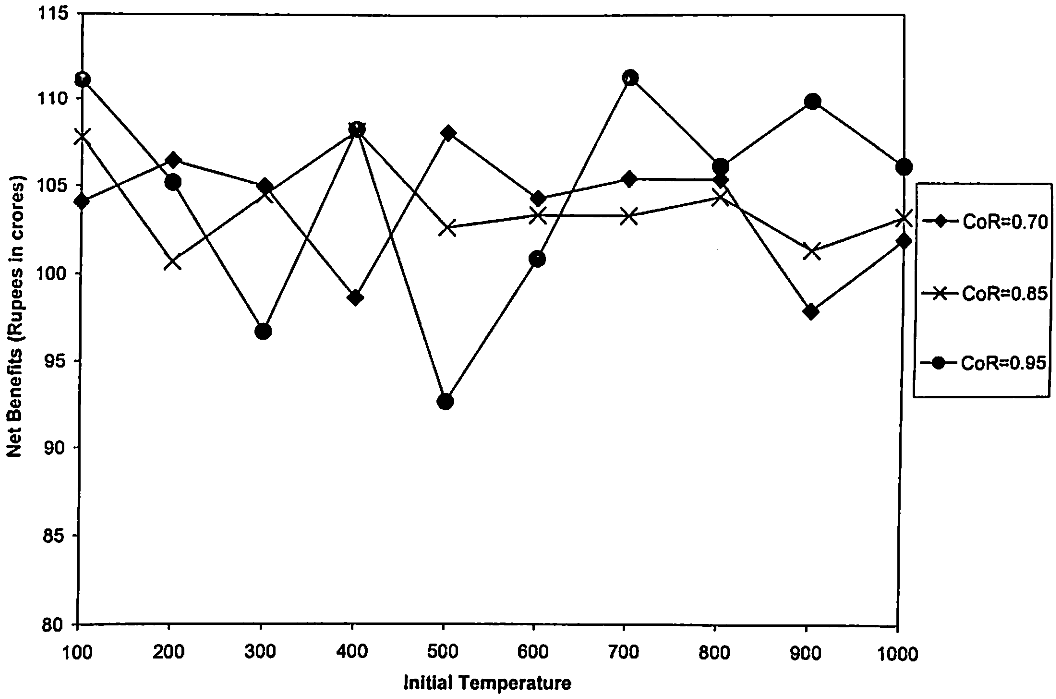

Fig. 6.75 Variation of net benefits for different cooling rates and initial temperature (NI=110)

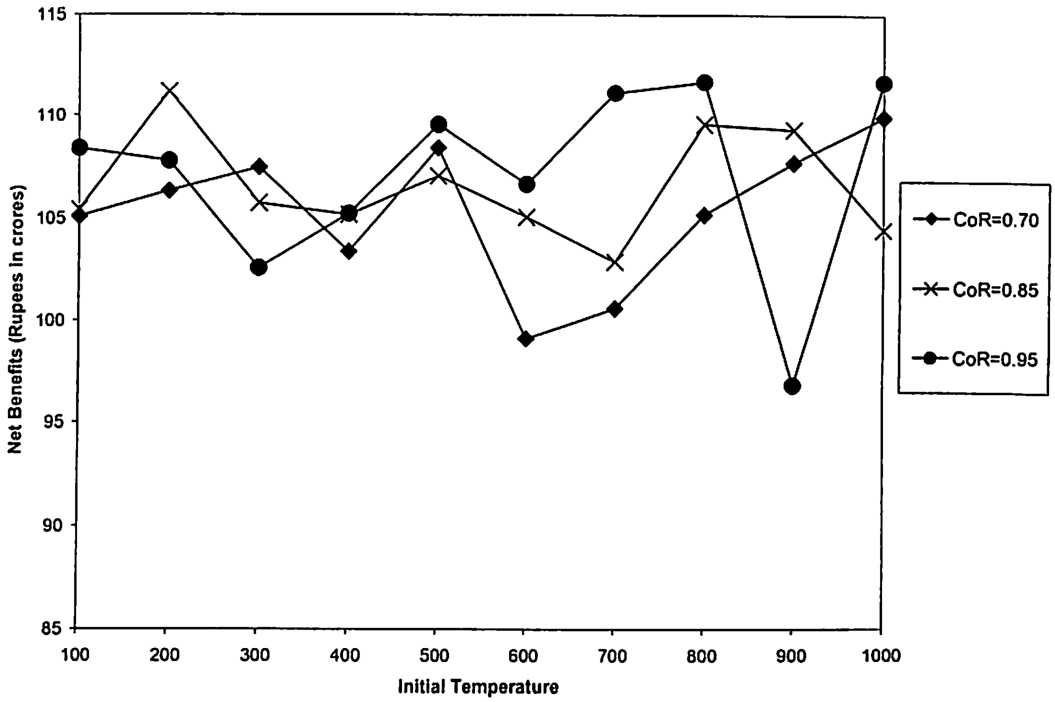

Fig. 6.74 Variation of net benefits for different cooling rates and initial temperature (NI=100)

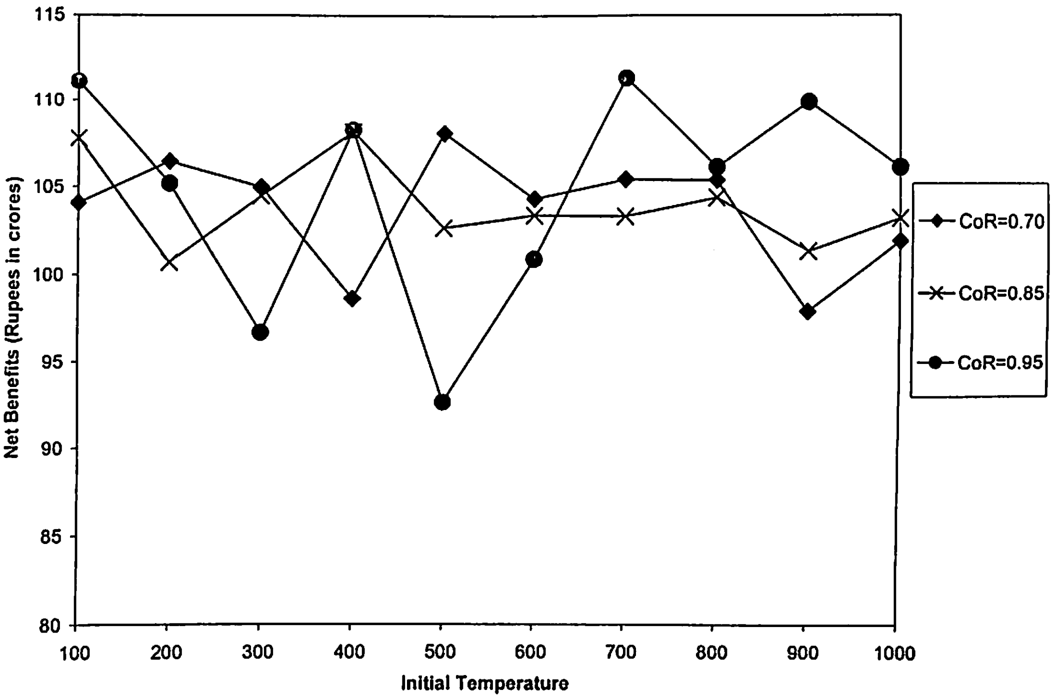

Fig. 6.75 Variation of net benefits for different cooling rates and initial temperature (NI=110)

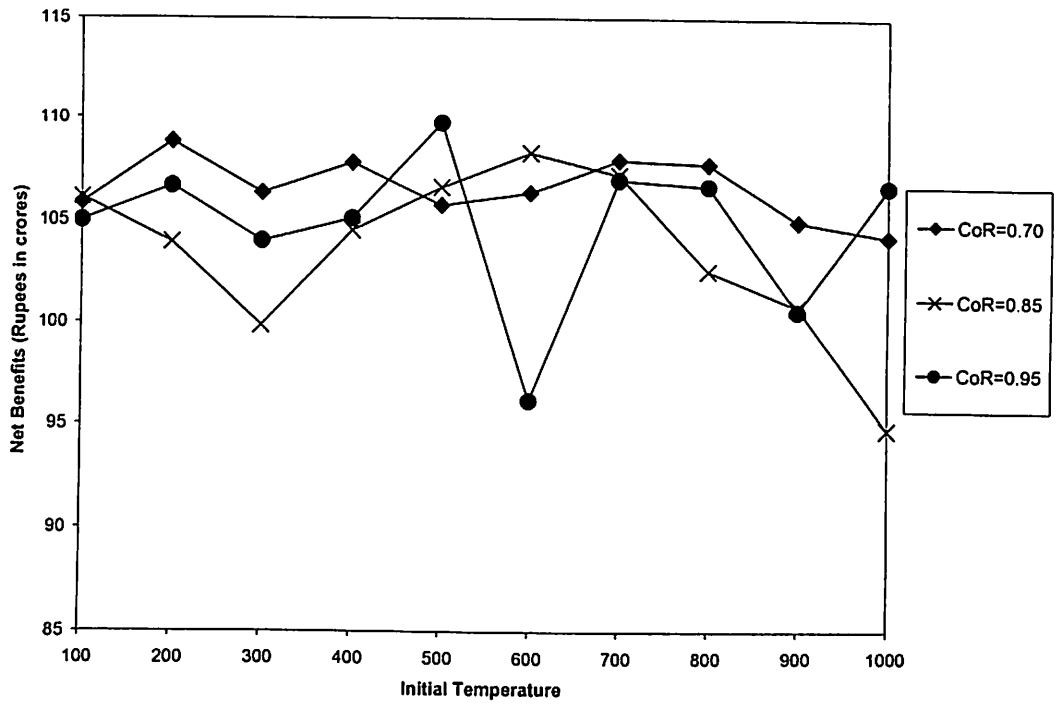

Fig. 6.72 Variation of net benefits for different cooling rates and initial temperature (NI=80)

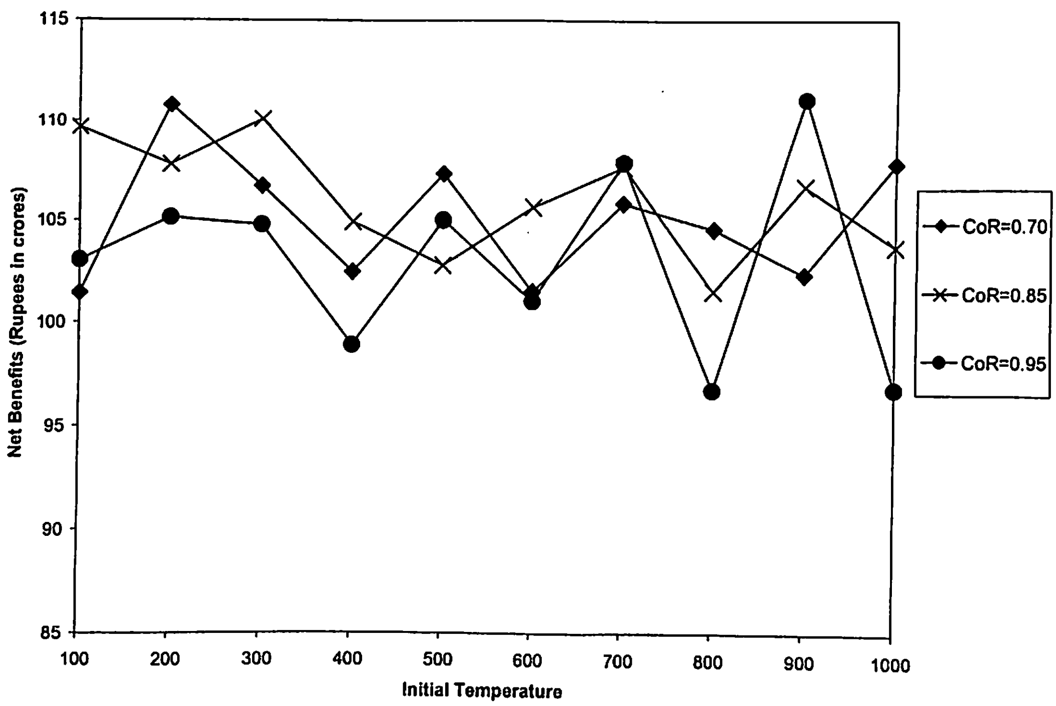

Fig. 6.73 Variation of net benefits for different cooling rates and initial temperature (NI=90)

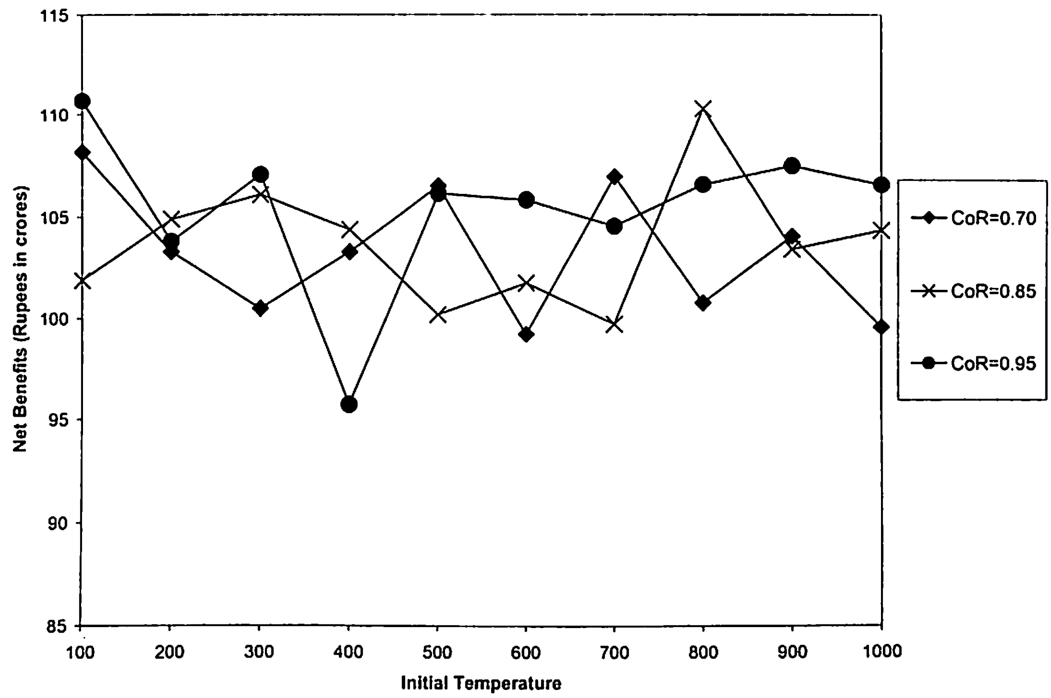

Fig. 6.76 Variation of net benefits for different cooling rates and initial temperature (NI=120)

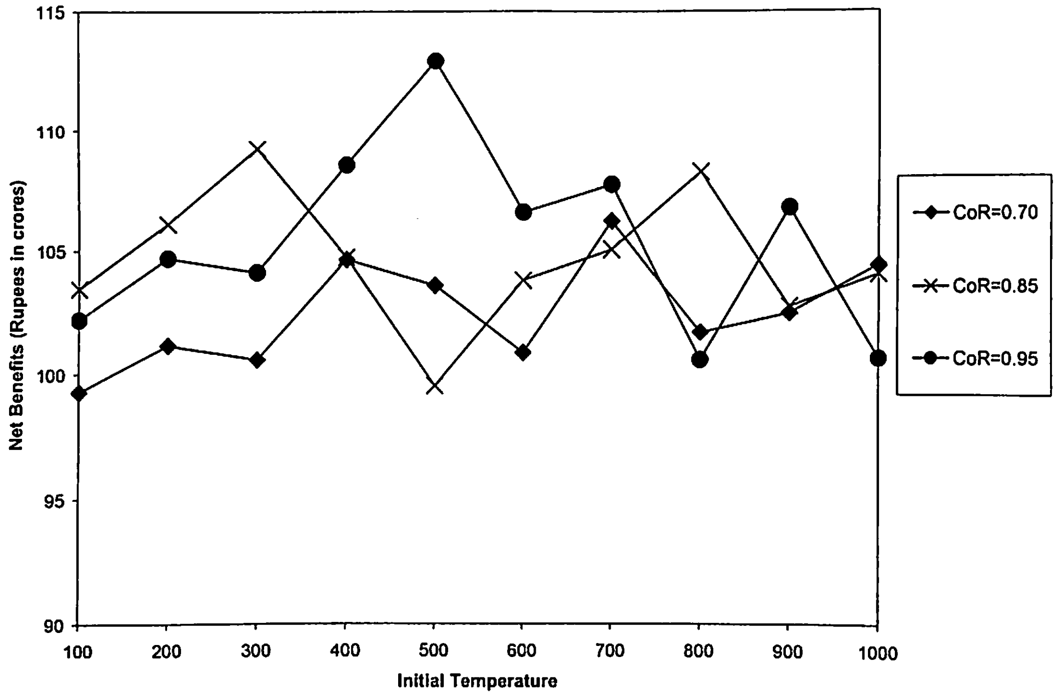

Fig. 6.77 Variation of net benefits for different cooling rates and initial temperature (NI=130)

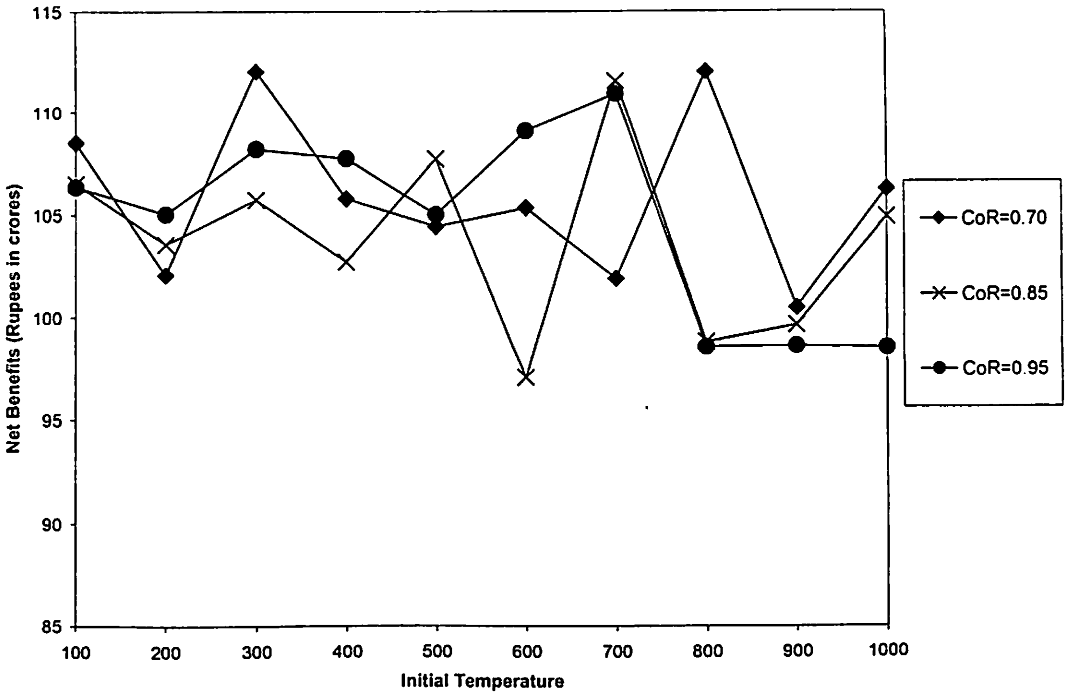

Fig. 6.78 Variation of net benefits for different cooling rates and initial temperature (NI=140)

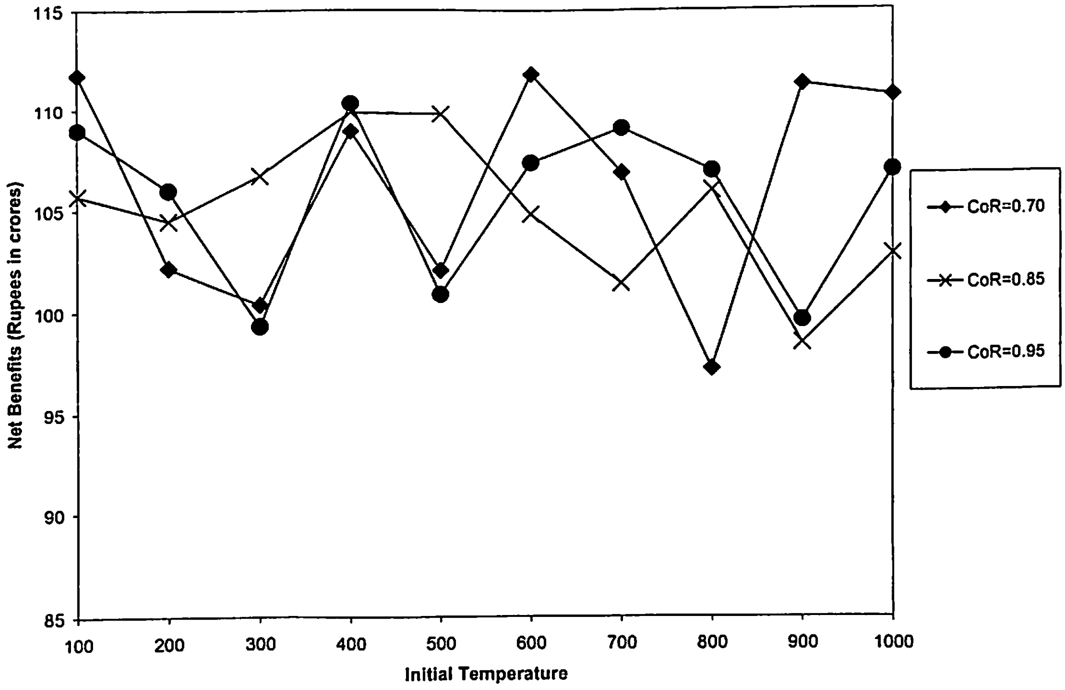

Fig. 6.79 Variation of net benefits for different cooling rates and initial temperature (NI=150)

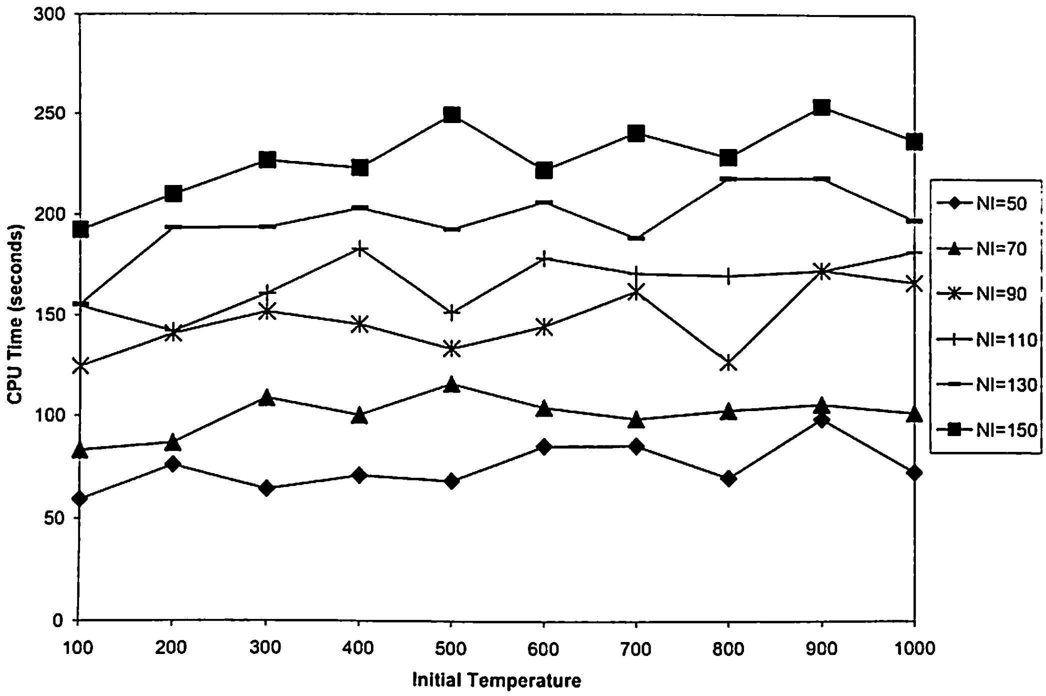

Fig. 6.80 CPU time variation for different number of iterations and initial temperature (CoR=0.70)

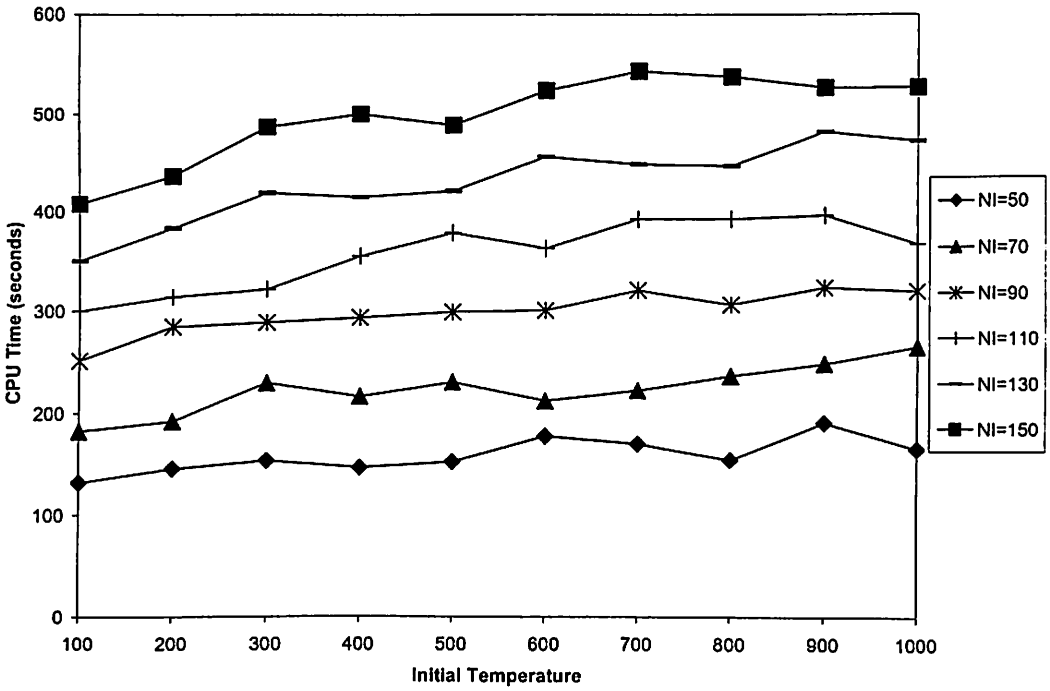

Fig. 6.81 CPU time variation for different number of iterations and initial temperature (CoR=0.85)

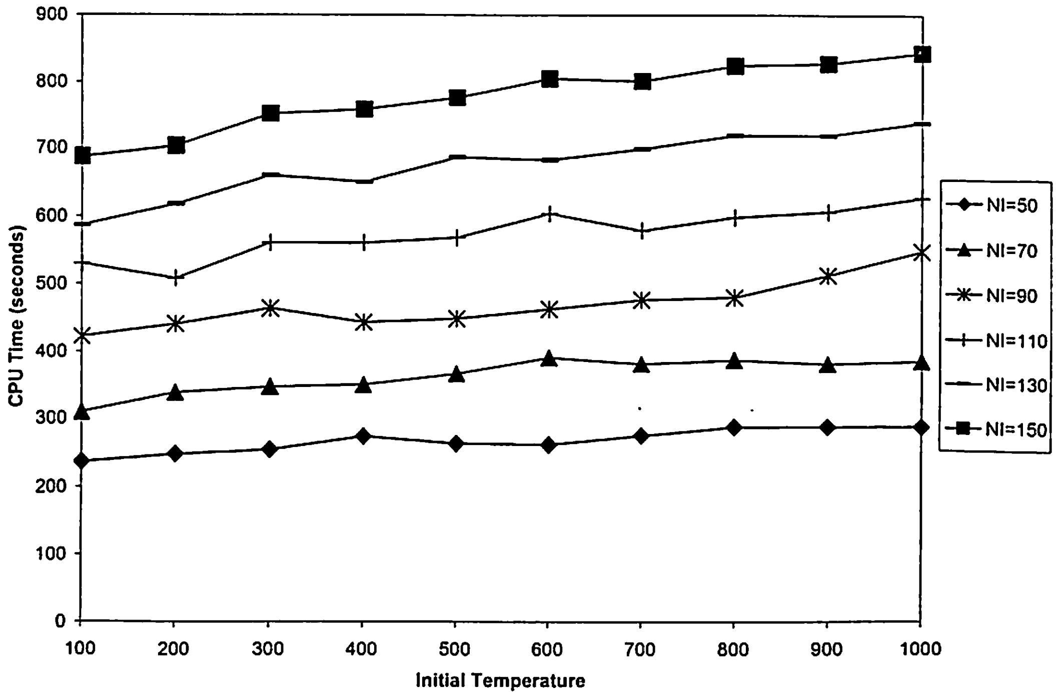

Fig. 6.82 CPU time variation for different number of iterations and initial temperature (CoR=0.95)

Type I - Variation of net benefits for different initial temperature and number of iterations for various cooling rates

- It is observed from Fig. 6.63 (CoR=0.70), Fig. 6.64 (CoR=0.75), Fig. 6.65 (CoR=0.80), Fig. 6.66 (CoR=0.85), Fig. 6.67 (CoR=0.90), Fig. 6.68 (CoR=0.95) that the variation of net benefits due to different initial temperature and number of iterations does not follow any pattern. Also no distinct relationship is observed among number of iterations, cooling rate and initial temperature. This may be due to its point-by-point search mechanism and the property of accepting or rejecting a generated point by Metropolis criterion (i.e., a better point having low energy would be accepted and the worst point having high energy would also be accepted with a probability).

Type II - Variation of net benefits for different initial temperature and cooling rates for number of iterations

- It is observed from Fig. 6.69 (NI=50), Fig. 6.70 (NI=60), Fig. 6.71 (NI=70), Fig. 6.72 (NI=80), Fig. 6.73 (NI=90), Fig. 6.74 (NI=100), Fig. 6.75 (NI=110), Fig. 6.76 (NI=120), Fig. 6.77 (NI=130), Fig. 6.78 (NI=140), Fig. 6.79 (NI=150) that the variation of net benefits due to different initial temperature and cooling rates does not follow any pattern and no distinct relationship is observed among the number of iterations, cooling rate and initial temperature.

Type III - CPU Time variation for different initial temperature and the number of iterations for various cooling rates

- It is observed from Fig. 6.80 (CoR=0.70) that CPU time requirements between initial temperature 100 to 1000 is apparently same for a given iteration. However, CPU time requirements for a given initial temperature increases with number of iterations. For initial temperature T=100, CPU time is 59.45 seconds (NI=50), 83.30 seconds (NI=70), 124.48 seconds (NI=90), 154.59 seconds (NI=110), 155.30 seconds (NI=130), 192.24 seconds (NI=150).
- It is observed from Fig. 6.81 (CoR=0.85) which is similar to Fig. 6.80 that CPU time increases with increase in the number of iterations.
- It is observed from Fig. 6.82 (CoR=0.95) that CPU time requirement increases with increase in the number of iterations for a given initial temperature which is similar to Fig. 6.80 (CoR=0.70) and Fig. 6.81 (CoR=0.85). It is also observed that there is an increase of CPU time requirement with increase in initial temperature for a given iteration with slight intermediate variations. For example, for NI=150, CPU time is 687.02 seconds (T=100), 702.38 seconds (T=200), 750.53 seconds (T=300), 757.34 seconds (T=400), 775.20 seconds (T=500), 804.30 seconds (T=600), 800.75 seconds (T=700), 823.47 seconds (T=800), 827.11 seconds (T=900), 843.47 seconds (T=1000).
- It is observed from Fig. 6.80 to Fig. 6.82 that as CoR increases, the CPU time requirement for a given initial temperature also increases. For example, for

T=100, NI=150, CoR=0.70 the maximum CPU time requirement is 192.24 seconds whereas it is 687.02 seconds for T=100, NI=150, CoR=0.95 combination.

Inferences:

- It is observed that variation of net benefits due to different initial temperatures, cooling rates and number of iterations does not follow any pattern and no distinct relationship is observed among the number of iterations, cooling rate and initial temperature.
- CPU time requirement increases with increase in the number of iterations for any cooling rate and initial temperature.
- It is observed that there is an increase of CPU time requirement with increase in initial temperatures for different number of iterations with slight intermediate variations.
- The CPU time requirement for a given initial temperature increases with increase in cooling rate for any number of iterations.

6.3.3.4 Simulated Quenching (SQ)

The parameters used for the study are number of iterations (NI'') varying from 50 to 150 with an increment of 10 (11 levels), initial temperature (T'') from 100 to 1000 with an increment of 100 (11 levels) and cooling rate (CoR'') from 0.70 to 0.95 with an increment 0.05 i.e., 6 levels (Ingber, 1993; Deb, 1995; Rao, 2003). The final temperature and the accuracy to be achieved between the successive iterations are fixed as 0.1 and 10^{-5}. The total number of resulting combinations is $11 \times 11 \times 6 = 726$.

The program is run for 726 combinations to determine the optimal set of parameters as explained in Section 6.3.3.1. From sensitivity analysis, the optimal set is found as NI''=110, T''=700 and CoR''=0.85 which yield net benefits of Rs.113.15 crores taking minimum CPU time of 418.99 seconds which is based on PC with Pentium IV 2.4GHz/256MB RAM/40GB HDD. Effect of variation of each parameter is shown in the form of graphs from Fig. 6.83 to 6.103.

The graphs are classified into three types and they are:

- Type I - Fig. 6.83 to Fig. 6.88 - Presents the variation of net benefits for different initial temperature (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000) and number of iterations (50, 70, 90, 110, 130, 150) for various cooling rates (0.70, 0.80, 0.85, 0.90, 0.95).
- Type II - Fig. 6.89 to Fig. 6.99 - Presents the variation of net benefits for different initial temperature (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000) and cooling rates (0.70, 0.85, 0.95) for the number of iterations (50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150).
- Type III - Fig. 6.100 to Fig. 6.102 - Presents the CPU time variation for different initial temperature (100, 200, 300, 400, 500, 600, 700, 800, 900, 1000) and number of iterations (50, 70, 90, 110, 130, 150) for various cooling rates (0.70, 0.85, 0.95). Due to the similar nature in graphs, the CPU time variation for cooling rate of 0.75, 0.80 and 0.90 are not presented.

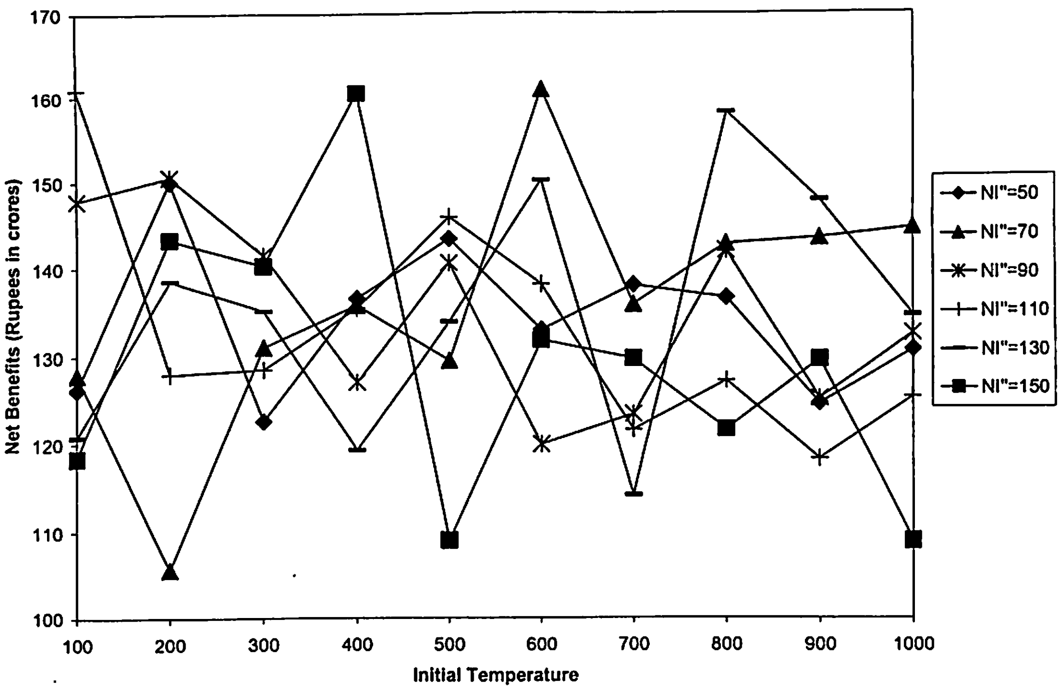

Fig. 6.83 Variation of net benefits for different number of iterations and initial temperature (CoR'' =0.70)

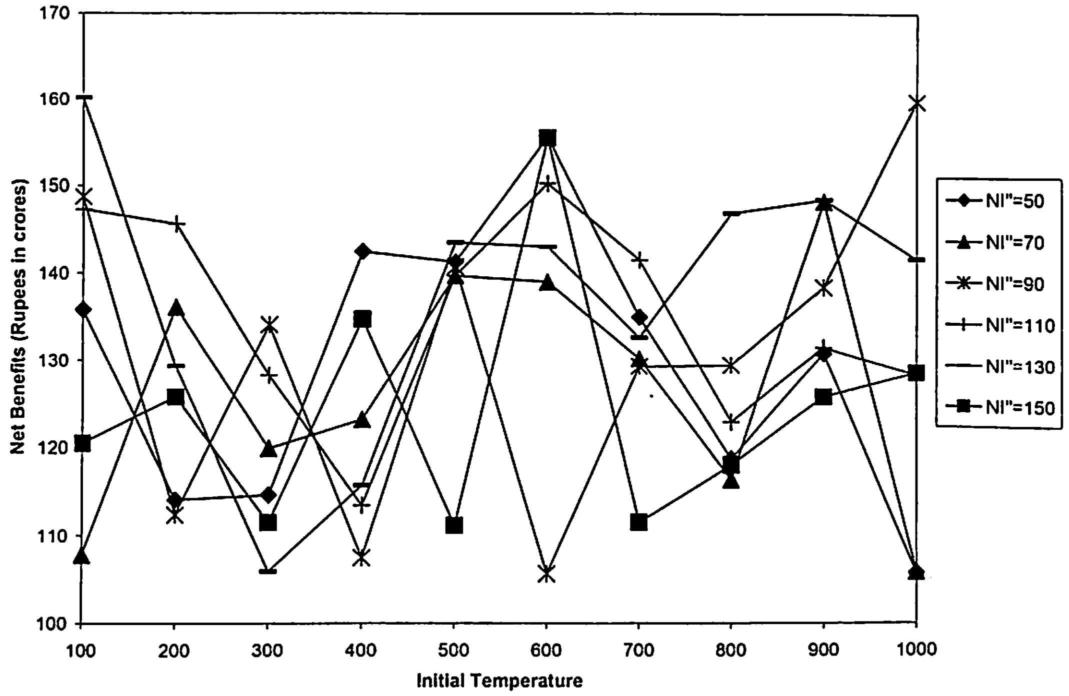

Fig. 6.84 Variation of net benefits for different number of iterations and initial temperature (CoR'' =0.75)

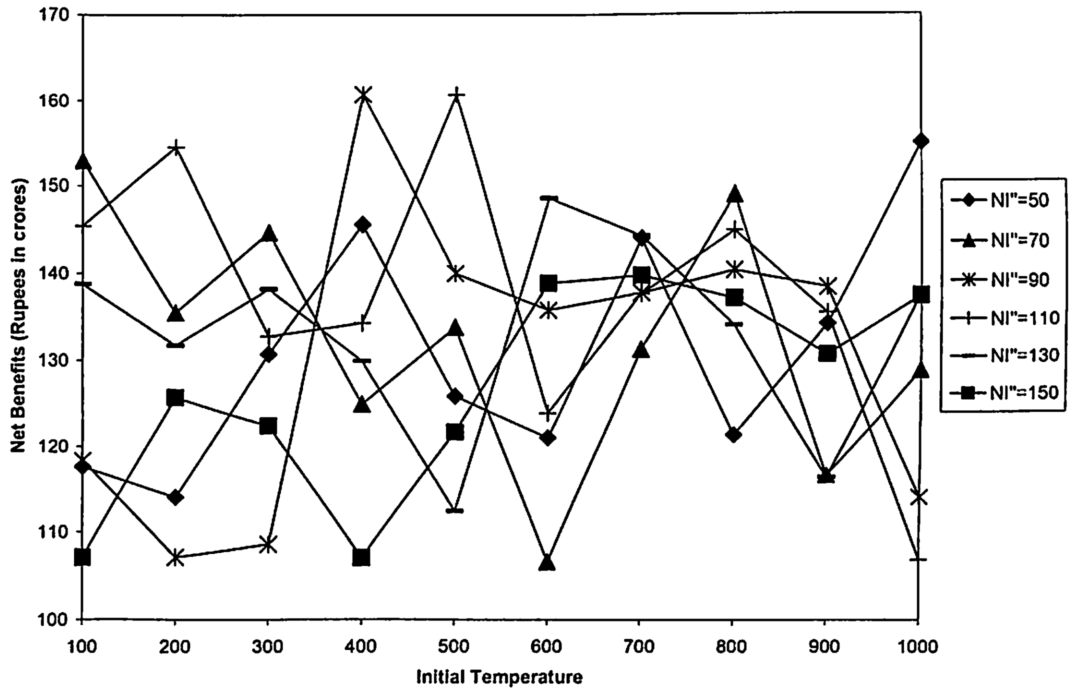

Fig. 6.85 Variation of net benefits for different number of iterations and initial temperature (CoR'' =0.80)

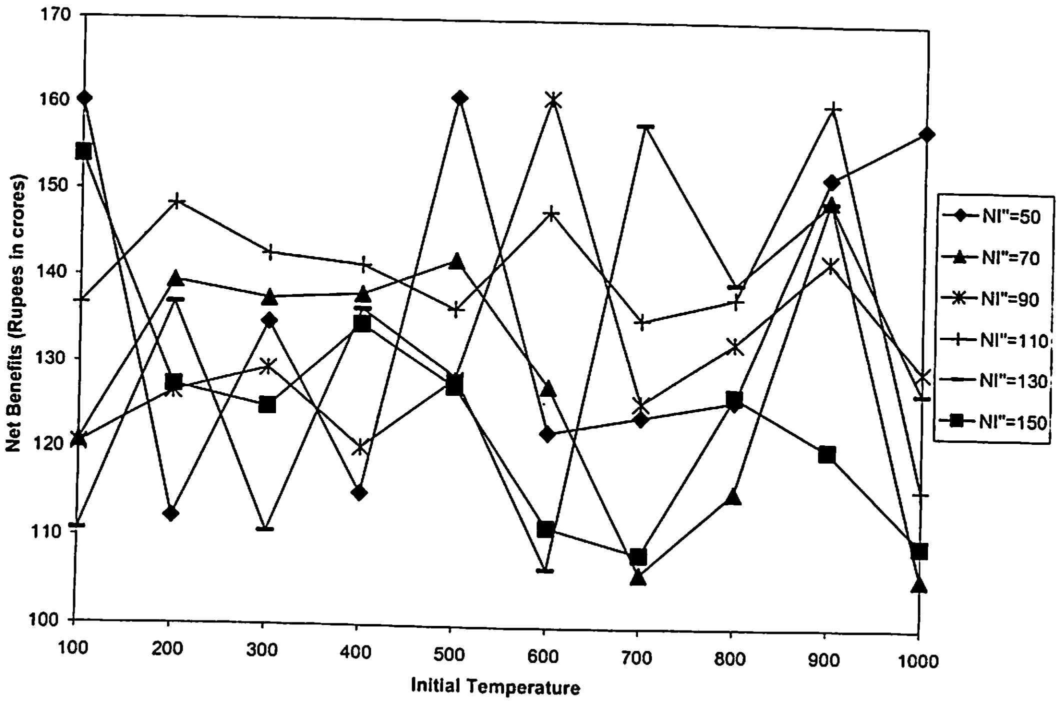

Fig. 6.86 Variation of net benefits for different number of iterations and initial temperature (CoR'' =0.85)

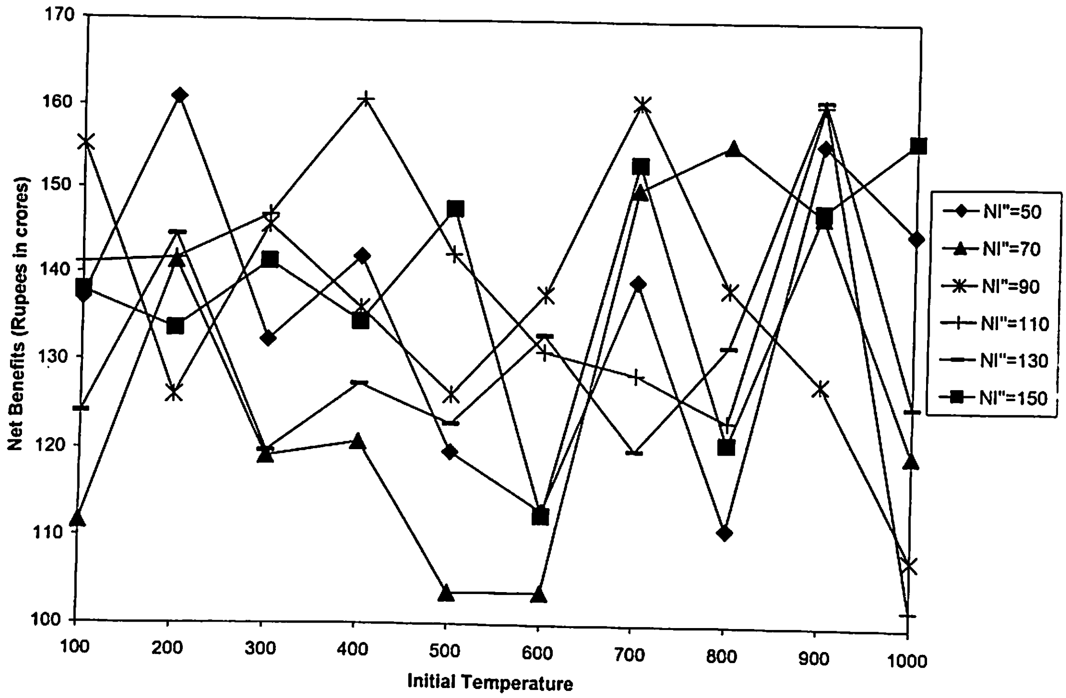

Fig. 6.87 Variation of net benefits for different number of iterations and initial temperature (CoR'' =0.90)

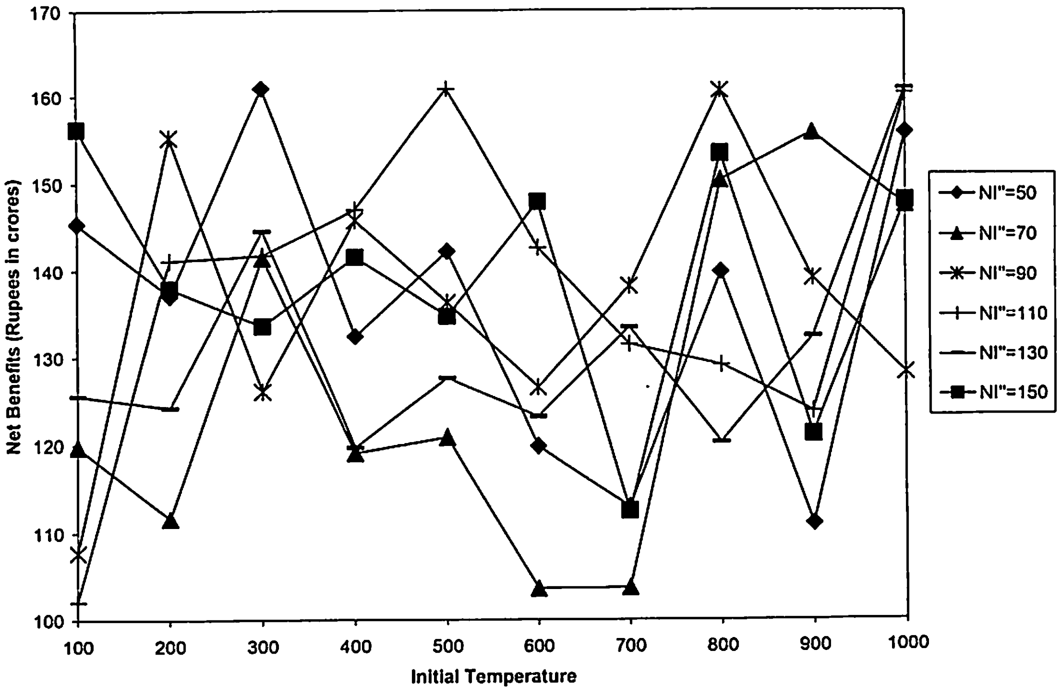

Fig. 6.88 Variation of net benefits for different number of iterations and initial temperature (CoR'' =0.95)

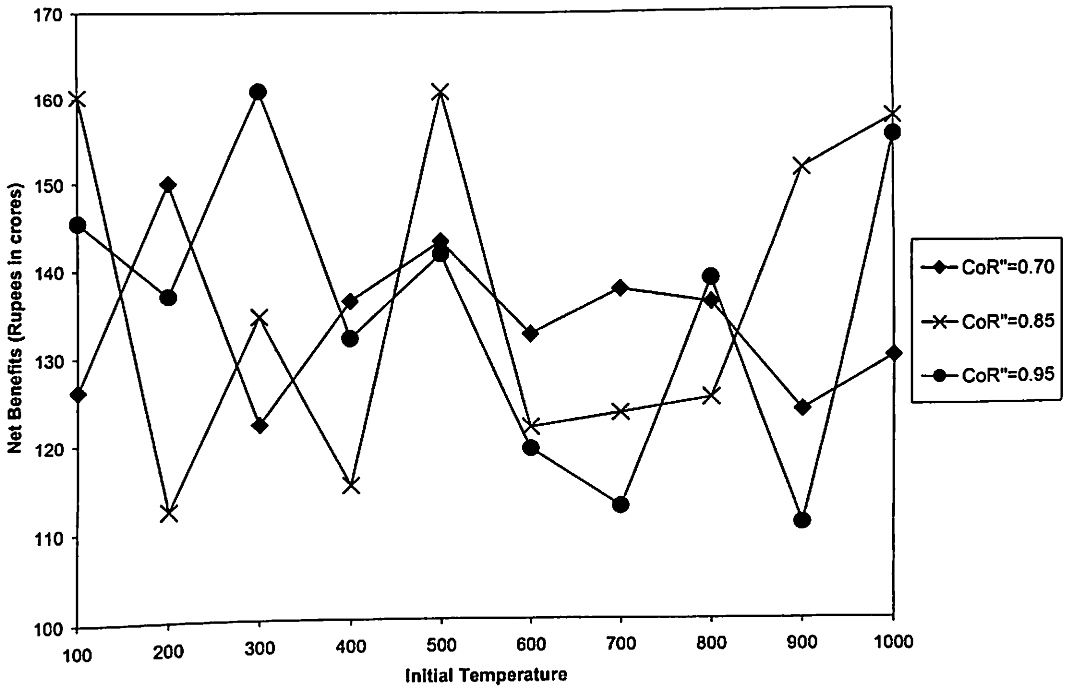

Fig. 6.89 Variation of net benefits for different cooling rates and initial temperature (NI'' =50)

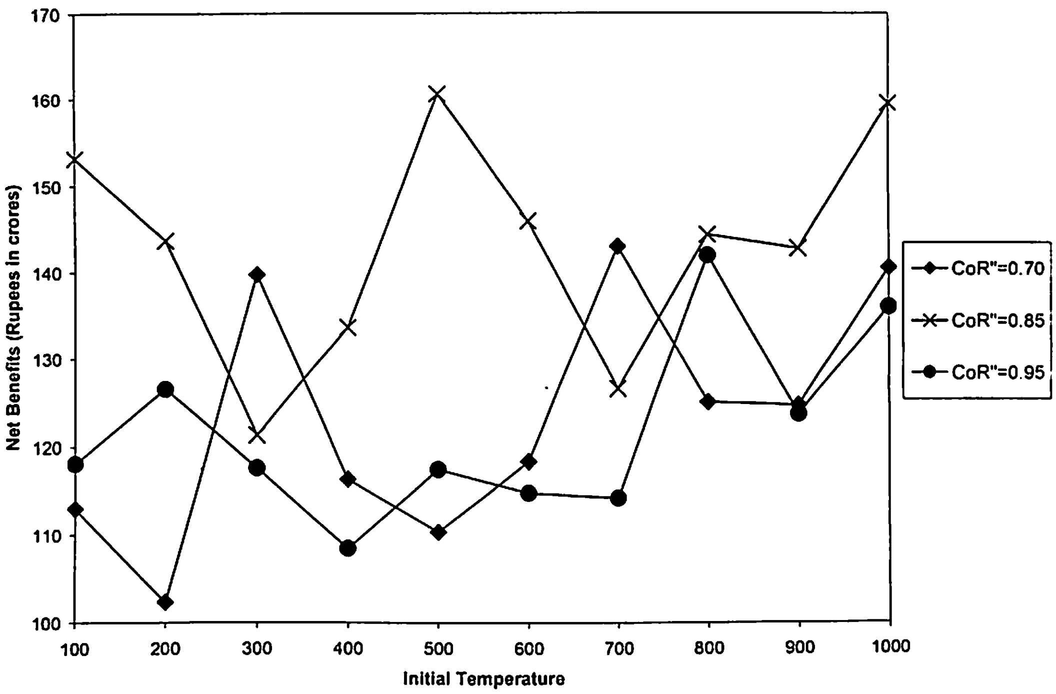

Fig. 6.90 Variation of net benefits for different cooling rates and initial temperature (NI''=60)

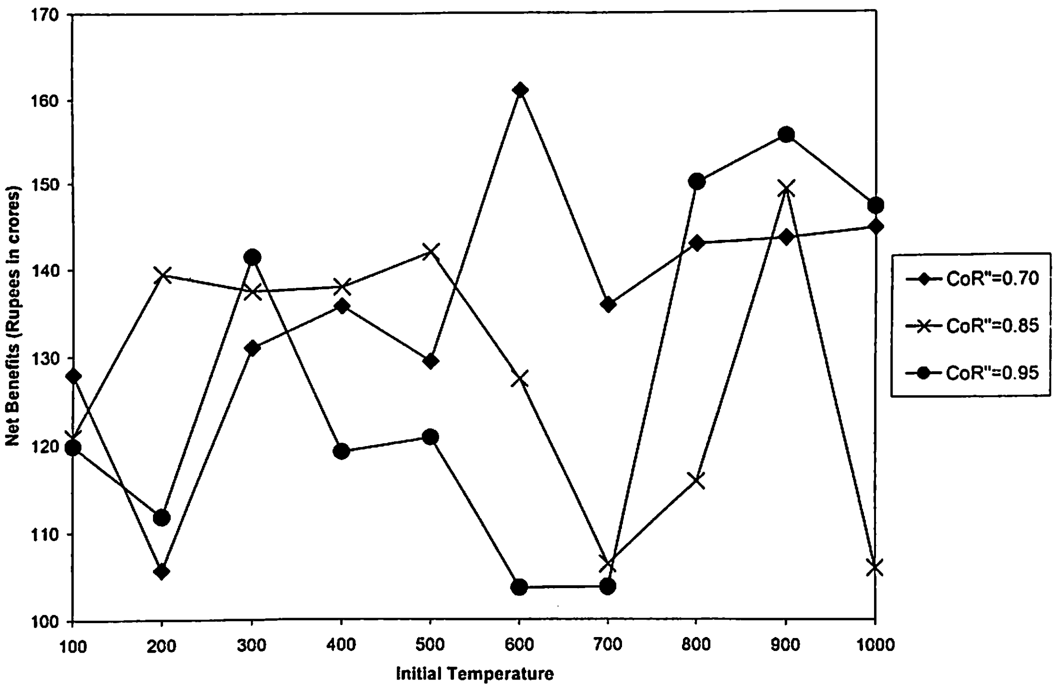

Fig. 6.91 Variation of net benefits for different cooling rates and initial temperature (NI''=70)

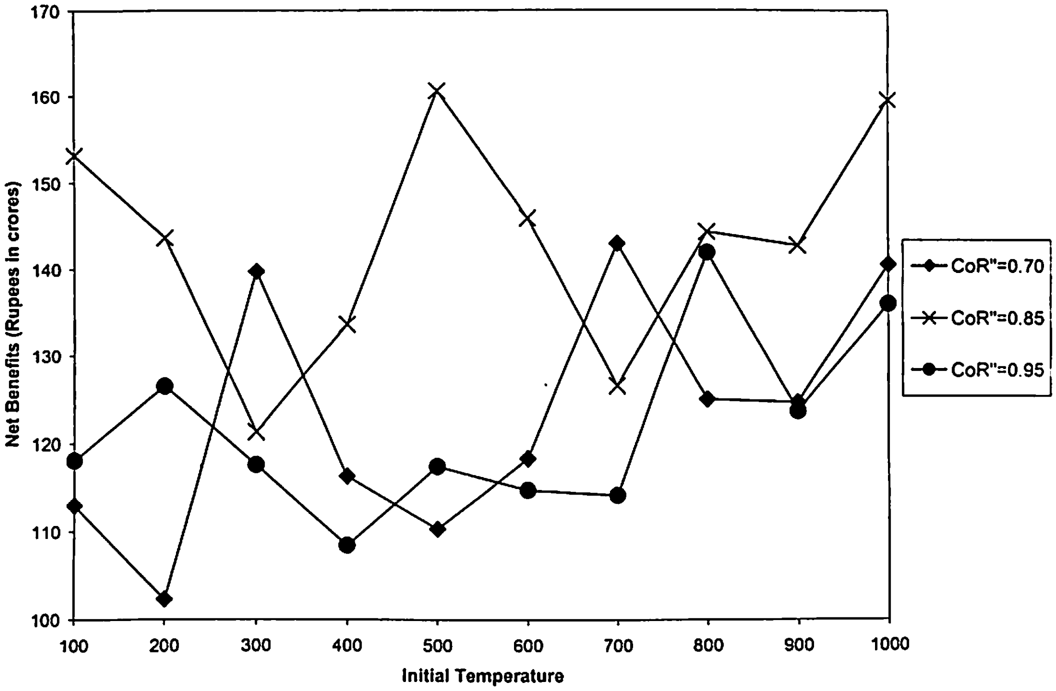

Fig. 6.90 Variation of net benefits for different cooling rates and initial temperature (NI'' =60)

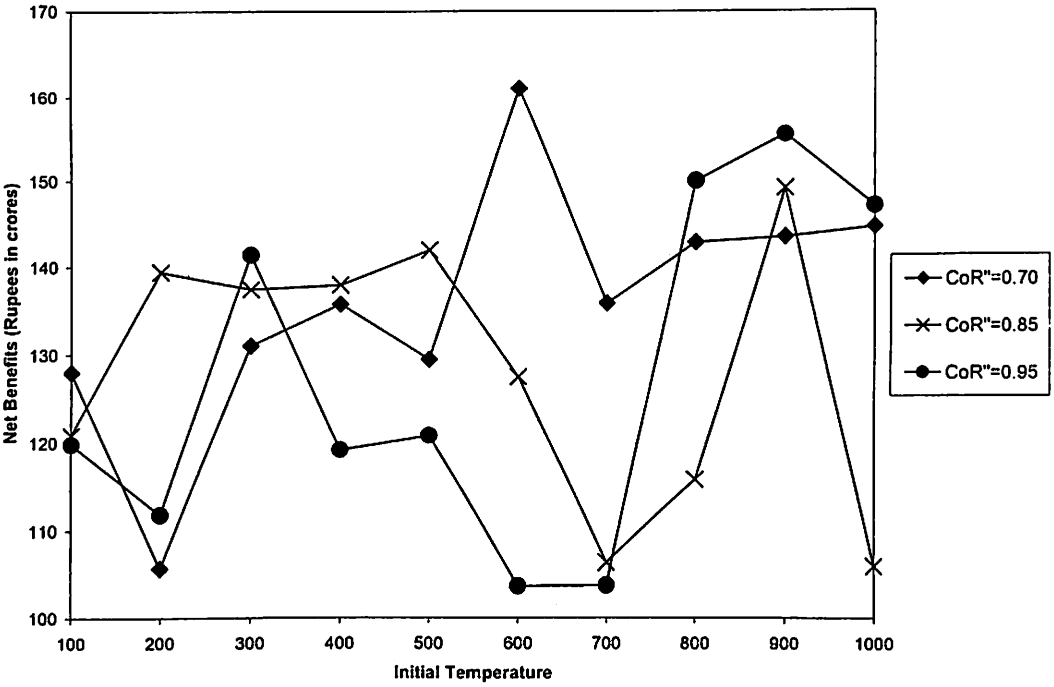

Fig. 6.91 Variation of net benefits for different cooling rates and initial temperature (NI'' =70)

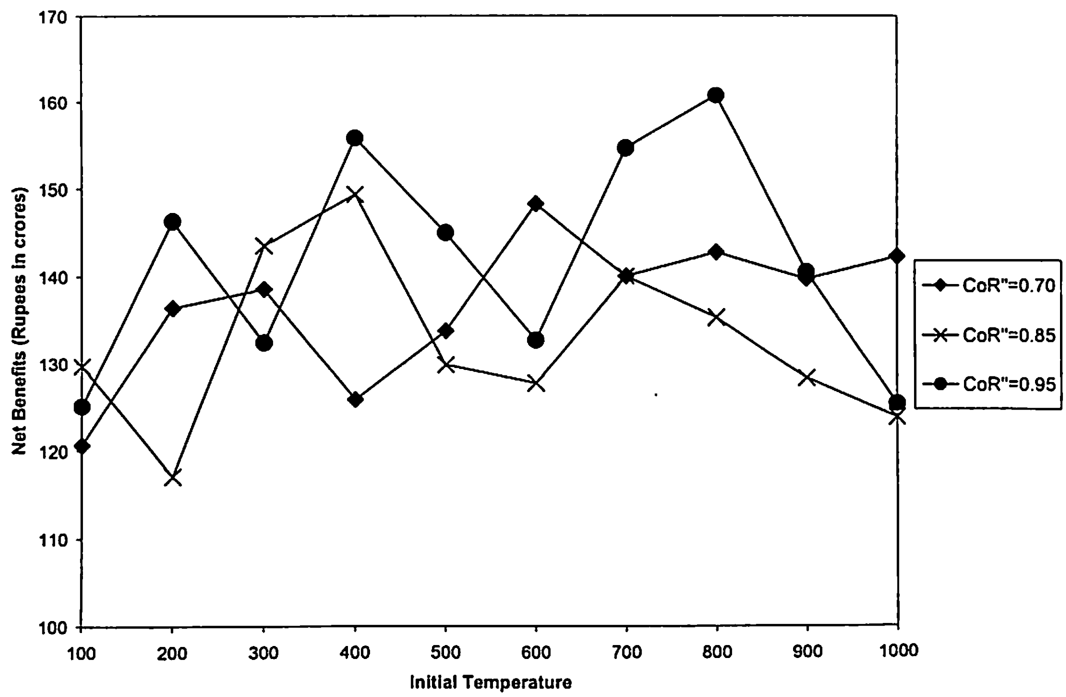

Fig. 6.92 Variation of net benefits for different cooling rates and initial temperature (NI'' =80)

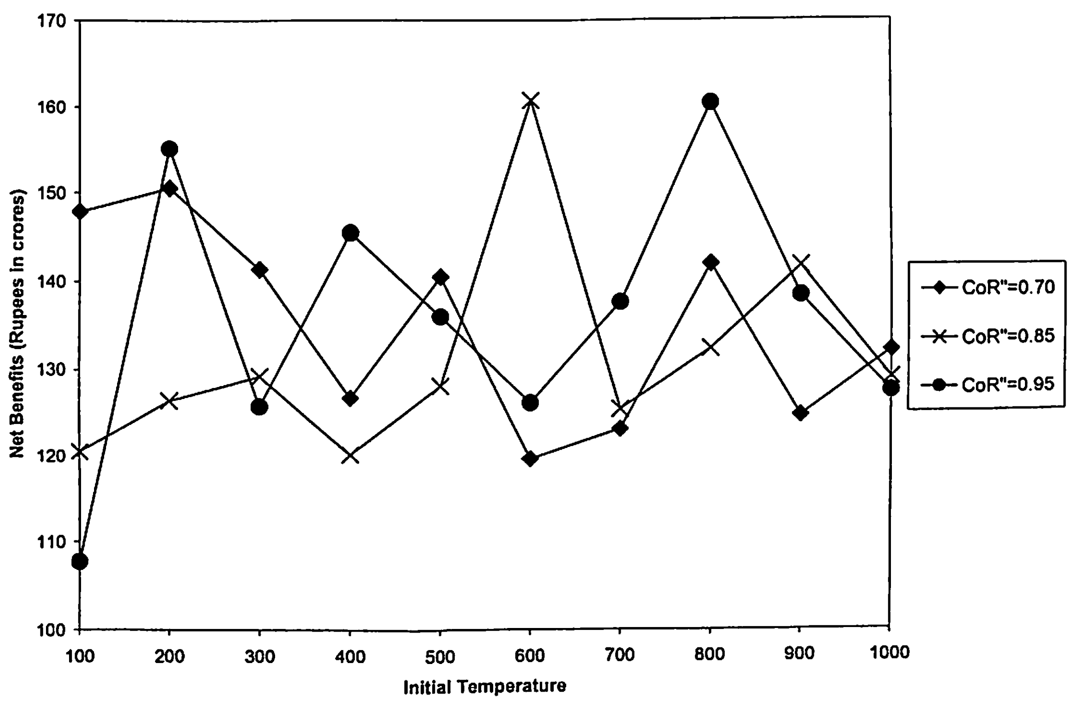

Fig. 6.93 Variation of net benefits for different cooling rates and initial temperature (NI'' =90)

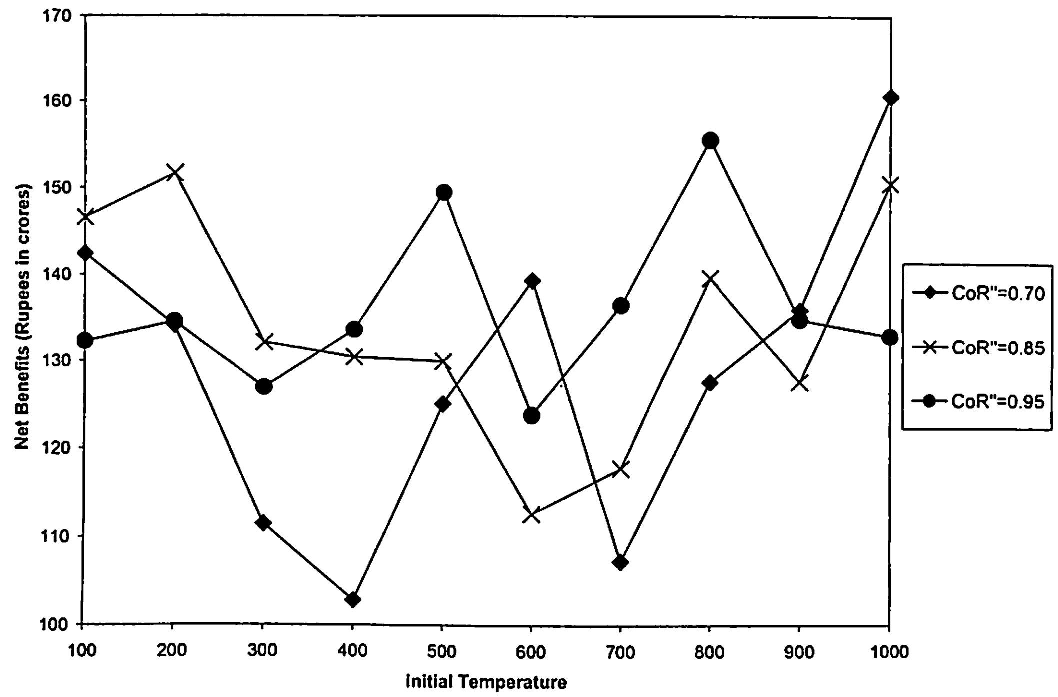

Fig. 6.94 Variation of net benefits for different cooling rates and initial temperature ($NI''=100$)

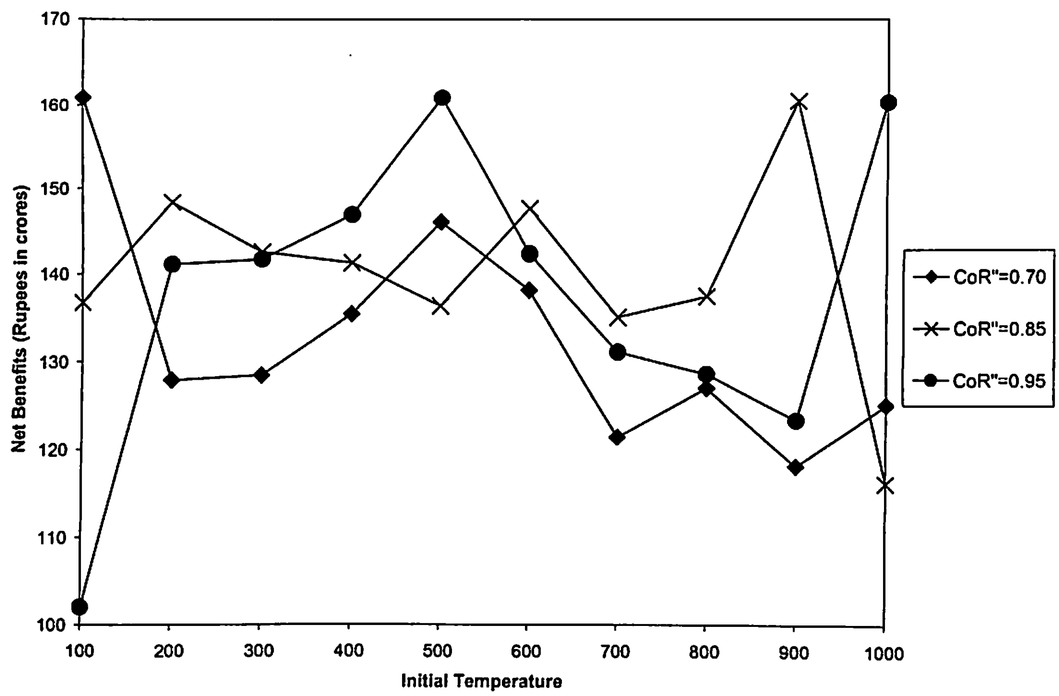

Fig. 6.95 Variation of net benefits for different cooling rates and initial temperature ($NI''=110$)

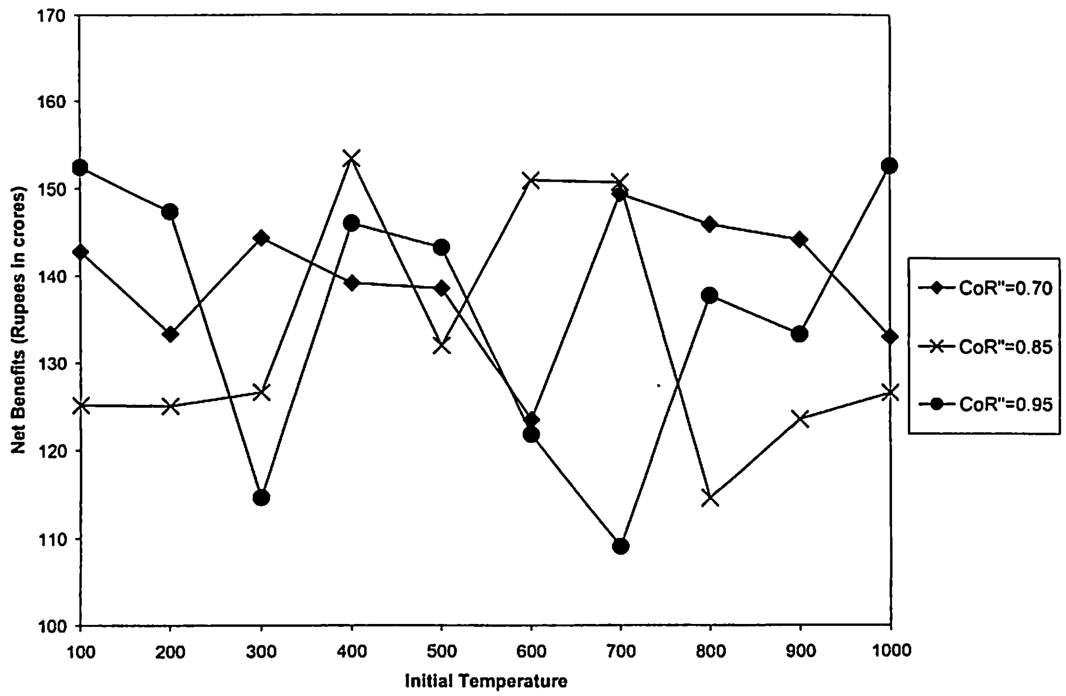

Fig. 6.96 Variation of net benefits for different cooling rates and initial temperature ($NI''=120$)

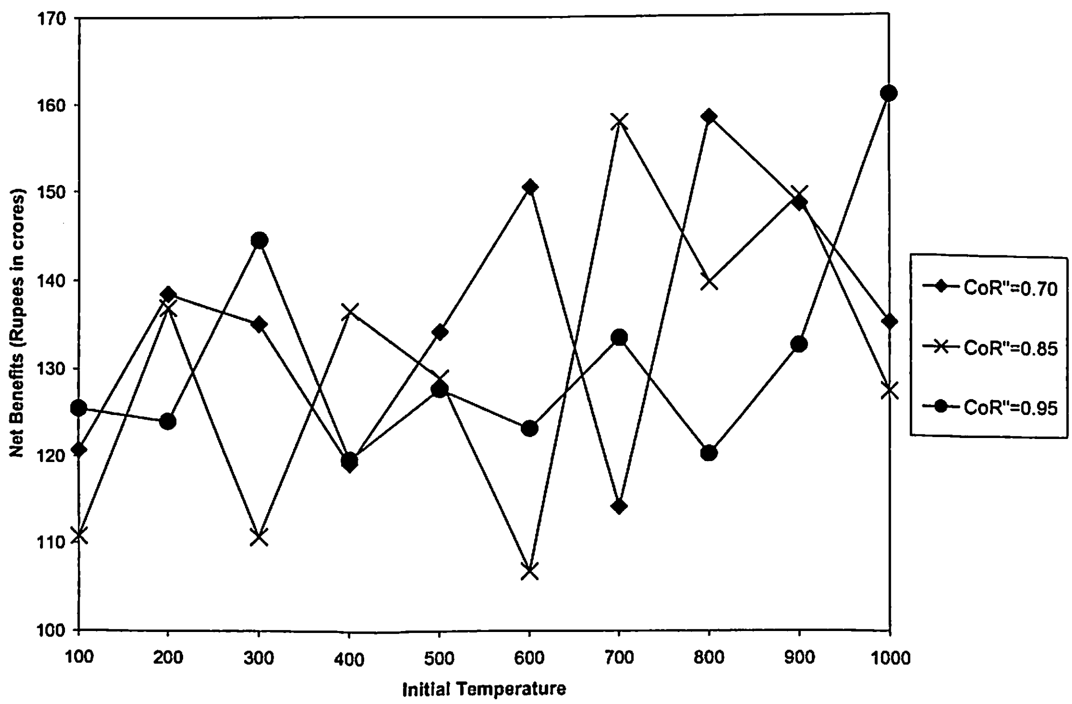

Fig. 6.97 Variation of net benefits for different cooling rates and initial temperature ($NI''=130$)

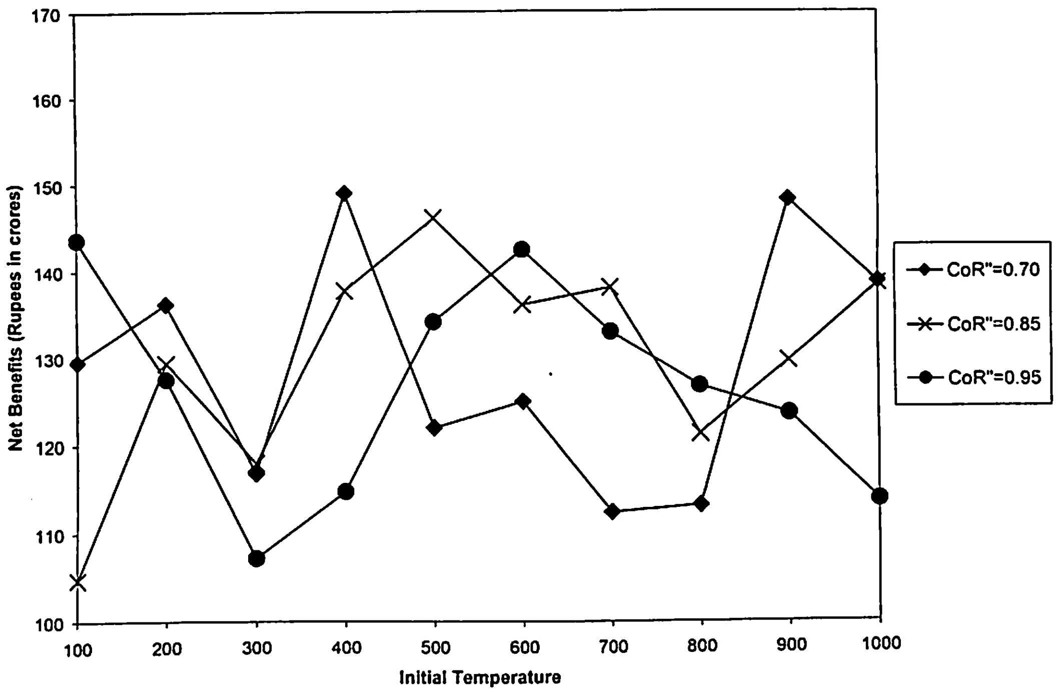

Fig. 6.98 Variation of net benefits for different cooling rates and initial temperature ($NI''=140$)

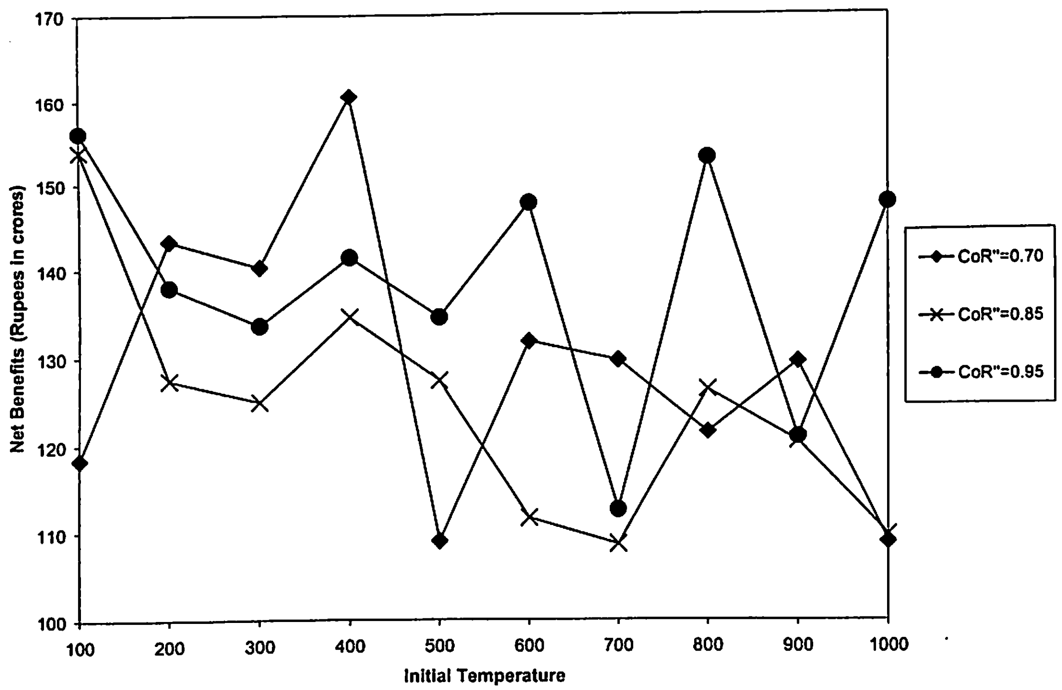

Fig. 6.99 Variation of net benefits for different cooling rates and initial temperature ($NI''=150$)

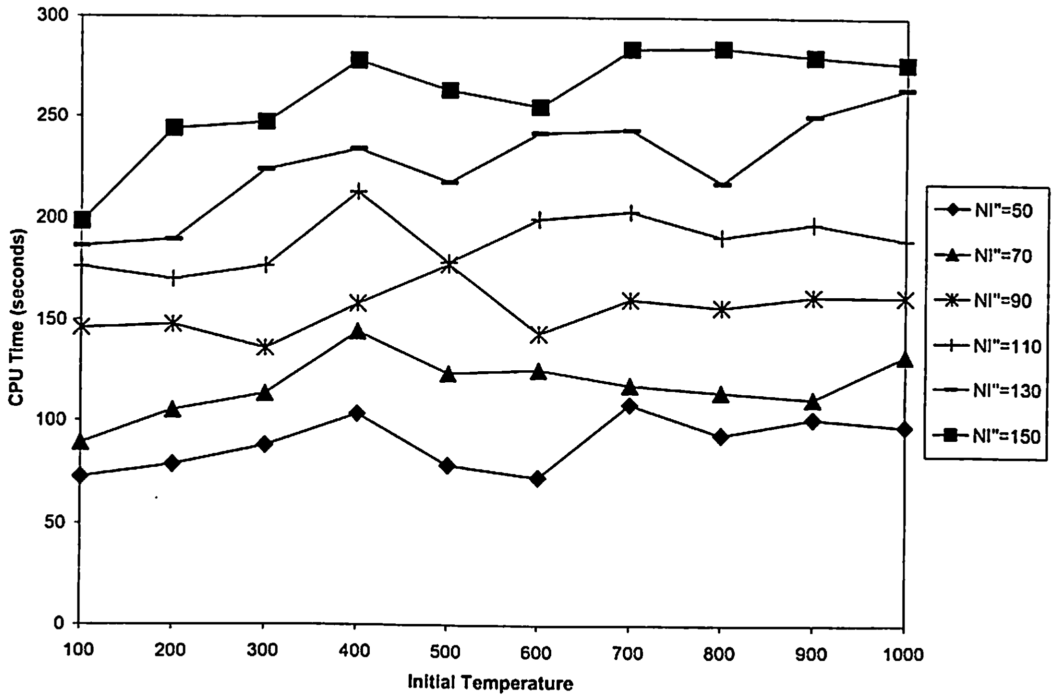

Fig. 6.100 CPU time variation for different initial temperature and number of iterations (CoR'' =0.70)

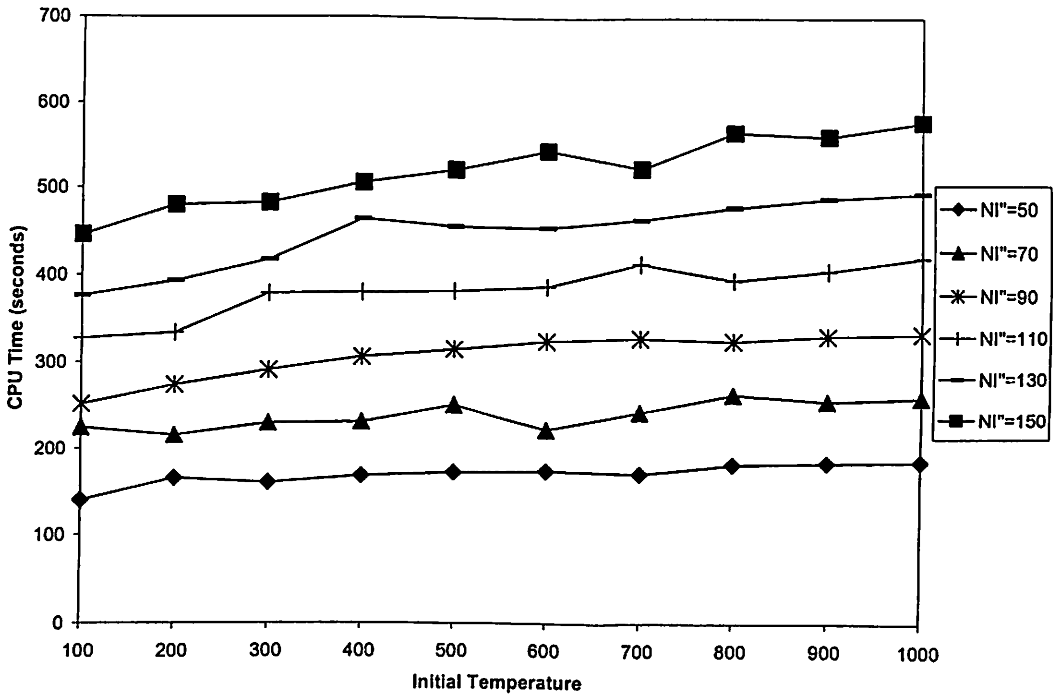

Fig. 6.101 CPU time variation for different initial temperature and number of iterations (CoR'' =0.85)

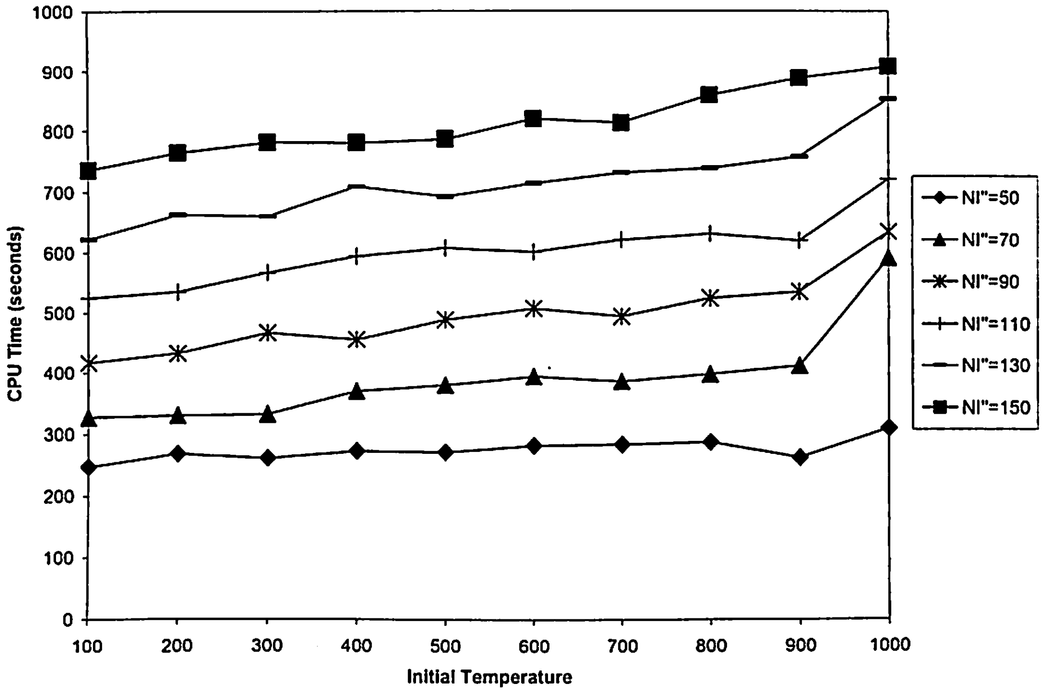

Fig. 6.102 CPU time variation for different initial temperature and number of iterations (CoR'' =0.95)

Type I - Variation of net benefits for different initial temperature and number of iterations for various cooling rates

- It is observed from Fig. 6.83 (CoR''=0.70), Fig. 6.84 (CoR''=0.75), Fig. 6.85 (CoR''=0.80), Fig. 6.86 (CoR''=0.85), Fig. 6.87 (CoR''=0.90), Fig. 6.88 (CoR''=0.95) that the variation of net benefits due to different initial temperature and number of iterations does not follow any pattern and no distinct relationship is observed among the number of iterations, cooling rate and initial temperature. This may be due to its point-by-point search mechanism and the property of accepting or rejecting a generated point by Metropolis criterion (i.e., a better point having low energy would be accepted and a worst point having high energy would also be accepted with a probability).

Type II - Variation of net benefits for different initial temperature and cooling rates for the number of iterations

- It is observed from Fig. 6.89 (NI''=50), Fig. 6.90 (NI''=60), Fig. 6.91 (NI''=70), Fig. 6.92 (NI''=80), Fig. 6.93 (NI''=90), Fig. 6.94 (NI''=100), Fig. 6.95 (NI''=110), Fig. 6.96 (NI''=120), Fig. 6.97 (NI''=130), Fig. 6.98 (NI''=140), Fig. 6.99 (NI''=150) that the variation of net benefits due to different initial temperature and cooling rates does not follow any pattern and no distinct relationship is observed among the number of iterations, cooling rate and initial temperature.

Type III - CPU Time variation for different initial temperature and number of iterations for various cooling rates

- It is observed from Fig. 6.100 (CoR''=0.70) that CPU time requirements for a given initial temperature increases with increase in the number of iterations ignoring intermediate variations. For example, for T''=100, CPU time is 72.75 seconds (NI''=50), 89.09 seconds (NI''=70), 145.98 seconds (NI''=90), 176.08 seconds (NI''=110), 186.25 seconds (NI''=130), 198.19 seconds (NI''=150).
- It is observed from Fig. 6.101 (CoR''=0.85) that CPU time increases with increase in the number of iterations.
- It is observed from Fig. 6.102 (CoR''=0.95) that CPU time increases with increase in number of iterations. It is also observed that there is an increase in CPU time with increase in initial temperature for a given iterations with slight intermediate variations. For example, for NI''=150, CPU time is 736.30 seconds (T''=100), 764.17 seconds (T''=200), 781.03 seconds (T''=300), 780.36 seconds (T''=400), 786.23 seconds (T''=500), 819.14 seconds (T''=600), 812.56 seconds (T''=700), 858.89 seconds (T''=800), 888.39 seconds (T''=900), 908.30 seconds (T''=1000).
- It is observed From Fig. 6.100 to Fig. 6.101 that as CoR'' increases, CPU time requirement for a given initial temperature also increases. For example, for

T''=100, NI''=150, CoR''=0.70 the maximum CPU time is 198.19 seconds whereas it is 736.30 seconds for T''=100, NI''=150, CoR''=0.95 combination.

Inferences:

- It is observed that variation of net benefits due to different initial temperatures, cooling rates and number of iterations does not follow any pattern and no distinct relationship is observed among the number of iterations, cooling rate and initial temperature.
- CPU time requirement increases with increase in the number of iterations for any cooling rate and initial temperature.
- It is observed that there is an increase of CPU time requirement with increase in initial temperatures for different number of iterations with slight intermediate variations.
- The CPU time requirement for a given initial temperature increases with increase in cooling rate for any number of iterations.

6.3.4 An Overview for Scenario 1

6.3.4.1 Optimal Parameters for Various Non-traditional Optimization Techniques

The optimal set of parameters obtained after analyzing 594, 3600, 726 and 726 combinations for RGA, DE, SA and SQ are presented in Table 6.16. It is observed from Table 6.16 that the number of generations 3000, population size of 1100, crossover probability of 0.9, distribution index of 2 for SBX, mutation probability of 0, distribution index of 100 for mutation are identified as the optimal set of parameters for RGA. In case of DE, the number of generations 3000, population size of 1100, crossover constant of 0.9, weighting factor of 0.6 for DE/rand-to-best/1/bin strategy are identified as the optimal combination. In case of SA, the number of iterations 130, initial temperature of 600, final temperature of 0.1, cooling rate of 0.90 are identified as the optimal combination. The optimal set of parameters for SQ is the number of iterations 110, initial temperature of 700, final temperature of 0.1 and cooling rate of 0.85. The CPU time requirements for RGA, DE, SA and SQ for optimal set of parameters as mentioned above are 108 seconds, 102.13 seconds, 685.38 seconds and 418.99 seconds respectively. It is observed that CPU time requirements for both SA and SQ are very high as compared to RGA and DE which may require further in depth analysis. The above optimal set of parameters may change depending on number of combinations performed and initial values chosen.

Table 6.16 Optimal set of parameters for four non-traditional optimization techniques

Optimization Technique	Number of Combinations	Optimal Set of Parameters
Real-coded Genetic Algorithms (RGA)	594 (POP-11 levels, XR-9 levels and MUT-6 levels)	Number of Generations = 3000 Population Size POP = 1100 Crossover Probability XR = 0.9 Distribution index for SBX = 2 Mutation Probability MUT = 0 Distribution index for parameter based mutation = 100
Differential Evolution (DE)	3600 (NP-10 levels, CR-6 levels, F-6 levels and 10 strategies)	Number of Generations = 3000 Population Size NP = 1100 Crossover Constant CR = 0.9 Weighting Factor F = 0.6 Strategy = DE/rand-to-best/1/bin
Simulated Annealing (SA)	726 (NI-11 levels, T-11 levels and CoR-6 levels)	Number of Iterations NI = 130 Initial Temperature T = 600 Final Temperature = 0.1 Cooling Rate CoR = 0.90
Simulated Quenching (SQ)	726 (NI''-11 levels, T''-11 levels and CoR''-6 levels)	Number of Iterations $NI'' = 110$ Initial Temperature $T'' = 700$ Final Temperature = 0.1 Cooling Rate $CoR'' = 0.85$

6.3.4.2 Comparison of Results Obtained by Five Solution Techniques for Optimal Set of Parameters (Scenario 1)

Results obtained by RGA, DE, SA and SQ for optimal set of parameters are compared with that of LP. It is observed that RGA, DE, SA and SQ produced the same results as that of LP. Table 6.17 presents the cropping pattern. Table 6.18 presents the releases policy for irrigation for LMC, RMC, BC. Fig. 6.103 presents the monthly storage policy values (including that of overflow) whereas Fig. 6.104 presents the release policy for hydropower in *PH 1*. The following observations are made from the analysis of the results:

1. **Cropping Pattern (LMC)**

(a) It is observed from Table 6.17 that Paddy, Cotton, Pulses, Zaid crop reaches the upper limit whereas Maize, Sugarcane has a percentage deviation of 23.09 and 23.06 respectively from upper limit.

(b) Similarly, Wheat, Gram, Mustard, Fruits and vegetables reaches the upper limit whereas Barley and Barseen deviate 23.12 % and 23.09 % respectively from upper limit.

(c) It is observed that the ratio of total area to lower limit (in percentage) is 126.32.

2. **Cropping Pattern (RMC)**

(a) It is observed that Maize (K), Sugarcane (K), Barley (R), Barseen (R) has an approximate deviation of 30 % respectively from upper limit whereas the other crops reaches the upper limit.

(b) It is observed that the ratio of total area to lower limit (in percentage) is 137.60.

3. **Cropping Pattern (BC)**

(a) In this case, only Cotton (K), Zaid crop (K) and Mustard (R) reach their upper limits.

(b) The ratio of total area to lower limit (in percentage) is 176.01.

4. **Cropping Pattern (Total area of LMC+RMC+BC) and Net Benefits**

(a) The total area irrigated is 67736 ha and corresponding maximum net benefits from the project is Rs.113.15 crores.

(b) The ratio of total area to lower limit (in percentage) is 132.28.

(c) It is also observed that net benefits per ha is Rs.16704.55 $\cong$ Rs.16705.

5. **Reservoir Operation**

(a) It is observed from Fig. 6.103 that empty storage is observed in the month of August and maximum live storage in the month of November.

1. **Cropping Pattern (LMC)**

(a) It is observed from Table 6.17 that Paddy, Cotton, Pulses, Zaid crop reaches the upper limit whereas Maize, Sugarcane has a percentage deviation of 23.09 and 23.06 respectively from upper limit.

(b) Similarly, Wheat, Gram, Mustard, Fruits and vegetables reaches the upper limit whereas Barley and Barseen deviate 23.12 % and 23.09 % respectively from upper limit.

(c) It is observed that the ratio of total area to lower limit (in percentage) is 126.32.

2. **Cropping Pattern (RMC)**

(a) It is observed that Maize (K), Sugarcane (K), Barley (R), Barseen (R) has an approximate deviation of 30 % respectively from upper limit whereas the other crops reaches the upper limit.

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(c) It is also observed that net benefits per ha is Rs.16704.55 $\cong$ Rs.16705.

5. **Reservoir Operation**

(a) It is observed from Fig. 6.103 that empty storage is observed in the month of August and maximum live storage in the month of November.

(b) It is observed from Table 6.18 that releases for irrigation for LMC, RMC, BC are high during the months of January, February and December whereas it is very low during the months of April and May.

(c) The annual releases (surface water) for LMC, RMC and BC are 303.65 Mm^3, 265.50 Mm^3 and 15.63 Mm^3.

(d) It is observed that monthly irrigation releases to LMC, RMC and BC are far less than the corresponding canal capacities.

(e) It is observed from Fig. 6.104 that maximum and minimum requirements for *PH 1* are during December and July.

6. Ground Water

It is observed that ground water withdrawal is during the months of January, February and July only which may help to augment the surface water.

Table 6.17 Cropping pattern obtained by the five techniques for optimal set of parameters for Scenario 1

Crops	Crop area in '00 ha			Percentage deviation from Upper Limit (%)
	Lower Limit	Upper Limit	Crop Area	
Maize (LMC) – K	9.36	12.17	9.36	23.09
Paddy (LMC) – K	12.48	16.23	16.23	0.00
Cotton (LMC) – K	28.07	36.51	36.51	0.00
Pulses (LMC) – K	15.60	20.29	20.29	0.00
Sugarcane (LMC) – K	6.24	8.11	6.24	23.06
Zaid Crop (LMC) – K	6.24	8.11	8.11	0.00
Area in Kharif (LMC)	77.99	101.42	96.74	4.61
Wheat (LMC) – R	93.57	121.71	121.71	0.00
Barley (LMC) – R	13.10	17.04	13.10	23.12
Gram (LMC) – R	78.60	102.24	102.24	0.00
Barseen (LMC) – R	5.93	7.71	5.93	23.09
Mustard (LMC) – R	6.86	8.93	8.93	0.00
Fruits & Veg. (LMC) – R	1.56	2.03	2.03	0.00
Area in Rabi (LMC)	199.62	259.66	253.94	2.20
Total Area (Kharif+Rabi) (LMC)	277.61	361.08	350.68	2.88
Ratio of Total Area to Lower Limit (LMC) (%)			126.32	-
Maize (RMC) – K	7.54	10.78	7.54	30.06

Crops	Crop area in '00 ha			Percentage deviation from Upper Limit (%)
	Lower Limit	Upper Limit	Crop Area	
Paddy (RMC) – K	10.06	14.38	14.38	0.00
Cotton (RMC) – K	22.63	32.35	32.35	0.00
Pulses (RMC) – K	12.57	17.97	17.97	0.00
Sugarcane (RMC) – K	5.03	7.19	5.03	30.04
Zaid Crop (RMC) – K	5.03	7.19	7.19	0.00
Area in Kharif (RMC)	62.86	89.86	84.46	6.01
Wheat (RMC) – R	75.42	107.82	107.82	0.00
Barley (RMC) – R	10.56	15.09	10.56	30.02
Gram (RMC) – R	63.36	90.57	90.57	0.00
Barseen (RMC) – R	4.78	6.83	4.78	30.01
Mustard (RMC) – R	5.53	7.91	7.91	0.00
Fruits & Veg. (RMC) – R	1.26	1.80	1.80	0.00
Area in Rabi (RMC)	160.91	230.02	223.44	2.86
Total Area (Kharif+Rabi) (RMC)	223.77	319.88	307.90	3.75
Ratio of Total Area to Lower Limit (RMC) (%)			137.60	-
Maize (BC) – K	0.36	1.05	0.36	65.71
Paddy (BC) – K	0.48	1.40	0.48	65.71
Cotton (BC) – K	1.08	3.14	3.14	0.00
Pulses (BC) – K	0.60	1.75	0.60	65.71
Sugarcane (BC) – K	0.24	0.70	0.24	65.71
Zaid Crop (BC) – K	0.24	0.70	0.70	0.00
Area in Kharif (BC)	3.00	8.74	5.52	36.84
Wheat (BC) – R	3.60	10.47	3.60	65.62
Barley (BC) – R	0.50	1.47	0.50	65.99
Gram (BC) – R	3.02	8.79	8.10	7.85
Barseen (BC) – R	0.23	0.66	0.23	65.15
Mustard (BC) – R	0.26	0.77	0.77	0.00
Fruits & Veg. (BC) – R	0.06	0.17	0.06	64.71
Area in Rabi (BC)	7.67	22.33	13.26	40.62
Total Area (Kharif+Rabi) (BC)	10.67	31.07	18.78	39.56
Ratio of Total Area to Lower Limit (BC) (%)			176.01	-
Total Area (Kharif) (LMC+RMC+BC)	143.85	200.02	186.72	6.65
Total Area (Rabi) (LMC+RMC+BC)	368.20	512.01	490.64	4.17
Total Area (Kharif+Rabi) (LMC+RMC+BC)	512.05	712.03	677.36	4.87
Ratio of Total Area to Lower Limit (LMC+RMC+BC) (%)			132.28	-

K-Kharif, R-Rabi, LMC-Left Main Canal, RMC-Right Main Canal, BC-Bhungra Canal

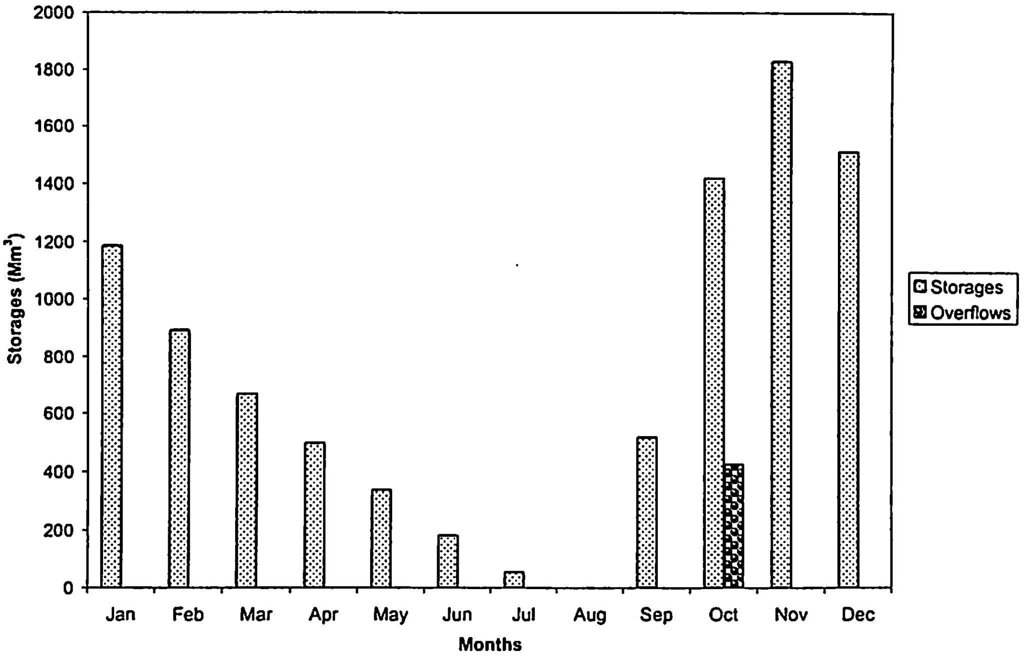

Fig. 6.103 Monthly storages and overflows obtained by the five techniques with optimal set of parameters for Scenario 1 (Mm^3)

Table 6.18 Release policy for irrigation for LMC, RMC and BC obtained by the five techniques with optimal set of parameters for Scenario 1 (Mm^3)

Month	SW			GW
	LMC	RMC	BC	
January	56.14	49.28	2.82	3.99
February	59.11	51.92	3.01	2.34
March	16.37	14.31	0.67	0.00
April	0.90	0.73	0.03	0.00
May	2.40	1.94	0.09	0.00
June	12.58	10.84	0.57	0.00
July	22.67	19.69	1.05	24.74
August	28.16	24.52	1.46	0.00
September	26.74	23.31	1.51	0.00
October	18.75	16.38	1.25	0.00
November	14.73	12.95	0.86	0.00
December	45.11	39.63	2.30	0.00
Total	303.65	265.50	15.63	31.07

LMC-Left Main Canal, RMC-Right Main Canal, BC-Bhungra Canal
SW-Surface Water, GW- Ground Water

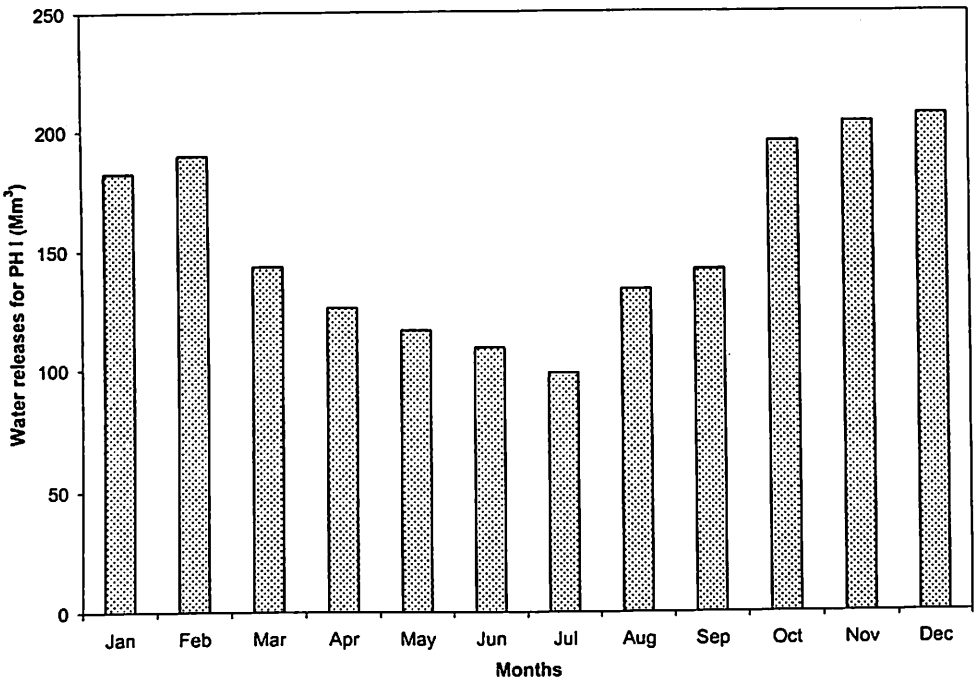

Fig. 6.104 Release policy for hydropower generation in *PH 1* obtained by the five techniques with optimal set of parameters for Scenario 1 (Mm^3)

Even though some of the observations are similar in nature, these are repeated again in relevant sections as these are the outcome of different methodologies such as (i) comparison of non-traditional techniques and LP, (ii) comparison of ten DE strategies and (iii) final outcome resulting from extensive sensitivity analysis for both Scenario 1 and Scenario 2.

6.4 SCENARIO 2

6.4.1 Comparison of Results Obtained by Five Solution Techniques (Scenario 2)

It is observed from Scenario 1 that 423.40 Mm^3 of water is unutilized and goes as overflow. The main reason for this may be due to high inflows during the months of September and October and infrastructural inability of the reservoir to store overflows. It is proposed that the reservoir storage can be increased to utilize the overflows and consequently increasing the annual net benefits from the project which is the basis for Scenario 2. In Scenario 2, the live storage of the reservoir is increased to 2000 Mm^3 (i.e., decrease of dead storage from 351.13 Mm^3 to 180.39 Mm^3). Also, lower and upper limits are fixed based on cropping intensity of 89% i.e., 89% of 57, 531 ha and 89% of 1,23,500 ha respectively (MBSP Report on Revised Project Estimate of Unit-II, 2001).

Developed mathematical model is solved by RGA, DE, SA and SQ using the optimum set of parameters (Table 6.16) obtained from sensitivity analysis of Scenario 1. These will be termed as chosen set for further use. Results obtained are compared with LP. Table 6.19 presents the cropping pattern for Left Main Canal (LMC), Right Main Canal (RMC) and Bhungra Canal (BC) and annual net benefits. Table 6.20 presents the storage policy obtained by five techniques. Table 6.21 presents the release policy for hydropower generation in *PH 1*. Tables 6.22, 6.23 and 6.24 presents the release policy for irrigation for LMC, RMC and BC. The following observations are made from the analysis of the results:

1. **Cropping Pattern (LMC)**
   (a) It is observed from Table 6.19 that the area of the crops in Kharif season has reached its upper limit for LP methodology.
   (b) The percentage deviation of crops that are grown in Kharif season with reference to upper limit (11250 ha) are 0, 0.52, 0.09, 3.08 and 17.08 for LP, RGA, DE, SA and SQ respectively. It is observed that the lowest deviation is of 0 % in case of LP and highest is of 17.08 % in case of SQ.

(c) The percentage deviation of area of crops that are grown in Rabi season as compared to upper limit are 0, 0.06, 0.05, 16.62 and 15.68 for LP, RGA, DE, SA and SQ respectively.

(d) It is observed from the total area (both Kharif and Rabi) that LP, RGA and DE yield similar values within a difference of 100 ha (40050 ha for LP, 39973 ha for RGA and 40025 ha for DE). There is significant difference of total area obtained by SA and SQ.

(e) The ratio of total area to lower limit (both Kharif and Rabi) is observed as 144.27 %, 143.99 %, 144.18 %, 125.77 % and 121.08 % for LP, RGA, DE, SA and SQ respectively.

2. **Cropping Pattern (RMC)**

(a) In case of Maize (K), low crop area is observed for SA solution methodology which is deviating 233 ha from the lower limit. The difference between SA and SQ is 2501 ha for Cotton (K).

(b) The percentage deviation of area of crops in Kharif season as compared to upper limit is 0, 0.12, 0.10, 32.13 and 2.00 for LP, RGA, DE, SA and SQ respectively.

(c) In case of Wheat (R), high crop area is observed for SA solution methodology i.e., 18204 ha whereas it is approximately 11450 ha for LP, RGA and DE. But, in case of Gram (R), low crop area is observed for SA i.e., 999 ha whereas it is 18903 ha, 18259 ha, 18645 ha and 14695 ha for LP, RGA, DE and SQ respectively.

(d) The percentage deviation of total area of crops (both Kharif and Rabi) as compared to upper limit is 21.15, 21.40, 21.33, 30.37 and 24.36 for LP, RGA, DE, SA and SQ respectively.

(e) The ratio of total area to lower limit in percentage (both Kharif and Rabi) is observed as 235.25, 234.50, 234.71, 207.72 and 225.65 for LP, RGA, DE, SA and SQ respectively.

3. **Cropping Pattern (BC)**

(a) The total area of crops (both Kharif and Rabi) that are obtained by LP, RGA, DE, SA, SQ are 3107 ha, 3072 ha, 3089 ha, 2248 ha, 2605 ha. It is observed that LP, RGA and DE yield similar values whereas SA and SQ yield similar values.

(b) The ratio of total area to lower limit (both Kharif and Rabi) is observed as 291.19 %, 287.91 %, 289.50 %, 210.68 % and 244.14 % for LP, RGA, DE, SA and SQ respectively.

4. **Cropping Pattern (Total area of LMC+RMC+BC)**

(a) Total area in Kharif is 30876 ha, 30772 ha, 30838 ha, 24278 ha, 28426 ha for LP, RGA, DE, SA, SQ whereas these are 64922 ha, 64748 ha, 64796 ha, 59367 ha, 58285 ha respectively in case of Rabi.

(b) It is found that percentage deviation of total area (both Rabi and Kharif) from its upper limit is 12.84, 13.10, 12.99, 23.90 and 21.11 for LP, RGA, DE, SA and SQ respectively.

(c) The ratio of total area to lower limit (both Kharif and Rabi) is 187.09 %, 186.54 %, 186.77 %, 163.35 % and 169.34 % for LP, RGA, DE, SA and SQ respectively.

(d) It is observed from the above result pattern that LP, RGA and DE can be considered as one group whereas SA and SQ can be considered as the other group. This also supports the theory that RGA, DE are population-based search techniques and SA, SQ are point-by-point search techniques.

5. **Reservoir Operation**

(a) It is observed from Table 6.20 that storage reached maximum live storage in the month of November.

(b) It is observed that overflows occurring in October are 212.72 Mm^3, 213.09 Mm^3, 212.98 Mm^3, 302.82 Mm^3 and 260.77 Mm^3 for LP, RGA, DE, SA and SQ respectively. This reduction in overflows is due to the additional storage created in reservoir by reducing the dead storage capacity.

(c) Table 6.21 presents release policy for hydropower generation for *PH 1* obtained by five solution techniques. It is observed that even though the monthly water releases obtained by various techniques are different, the annual releases obtained by LP, RGA and DE are similar whereas these are different for SA and SQ. Among SA and SQ, releases made by SQ are more.

(d) Table 6.22 presents annual surface water releases for LMC as obtained by five solution techniques. These are similar for LP, RGA and DE (around 351 Mm^3). In case of SA and SQ, these are 308.67 Mm^3 and 290.46 Mm^3 respectively.

(e) Table 6.23 presents annual surface water releases for RMC as obtained by five solution techniques. These are around 474 to 477 Mm^3 in case of LP, RGA, DE and SQ and 413.29 Mm^3 in case of SA.

(f) It is observed that the releases to RMC reaches its maximum capacity of 78.89 Mm^3 during February by LP, RGA, DE and SA.

(g) Table 6.24 presents annual surface water releases for Bhungra canal as obtained by five solution techniques. These are similar in case of LP, RGA and DE (around 27 Mm^3). These are 19.89 Mm^3, 22.75 Mm^3 in case of SA and SQ respectively.

6. Ground Water

Conjunctive use of water resources (in the form of ground water contribution) is not warranted due to the adequate amount of water in the reservoir.

7. Net Benefits

The values of net benefits are Rs.163.20 crores, Rs.162.22 crores, Rs.162.74 crores, Rs.140.31 crores and Rs.147.50 crores for LP, RGA, DE, SA and SQ respectively as observed from Table 6.19.

The above results are based on the optimal set of parameters obtained from Scenario 1. It is observed that careful selection of parameters is very important to come to a conclusion. This aspect is handled by extensive sensitivity analysis for Scenario 2 as discussed in section 6.4.3. Section 6.4.2 presents comparison of results obtained by ten DE strategies.

Table 6.19 Cropping pattern obtained by the five techniques

Crops	Crop area in '00 ha						
	Lower Limit	Upper Limit	LP	RGA	DE	SA	SQ
Maize (LMC) – K	9.36	13.50	13.50	13.50	13.49	13.21	10.50
Paddy (LMC) – K	12.48	18.00	18.00	18.00	17.99	17.94	12.70
Cotton (LMC) – K	28.07	40.50	40.50	40.49	40.49	40.49	33.80
Pulses (LMC) – K	15.60	22.50	22.50	22.50	22.50	22.00	22.47
Sugarcane (LMC) – K	6.24	9.00	9.00	9.00	9.00	6.57	7.06
Zaid Crop (LMC) – K	6.24	9.00	9.00	8.42	8.93	8.82	6.75
Area in Kharif (LMC)	77.99	112.50	112.50	111.91	112.40	109.03	93.28
Wheat (LMC) – R	93.57	135.00	135.00	134.99	134.96	100.86	95.23
Barley (LMC) – R	13.10	18.90	18.90	18.87	18.89	18.58	18.85
Gram (LMC) – R	78.60	113.40	113.40	113.38	113.37	105.39	113.40
Barseen (LMC) – R	5.93	8.55	8.55	8.55	8.52	6.61	6.13
Mustard (LMC) – R	6.86	9.90	9.90	9.82	9.87	7.02	7.10
Fruits & Veg. (LMC) – R	1.56	2.25	2.25	2.21	2.24	1.67	2.13
Area in Rabi (LMC)	199.62	288.00	288.00	287.82	287.85	240.13	242.84
Total Area (Kharif+Rabi) (LMC)	277.61	400.50	400.50	399.73	400.25	349.16	336.12
Maize (RMC) – K	7.54	22.50	22.50	22.50	22.50	9.87	22.48
Paddy (RMC) – K	10.06	30.00	30.00	29.99	30.00	29.90	29.96
Cotton (RMC) – K	22.63	67.51	67.51	67.51	67.49	42.50	67.51
Pulses (RMC) – K	12.57	37.51	37.51	37.49	37.49	15.82	37.51
Sugarcane (RMC) – K	5.03	15.00	15.00	14.98	14.99	14.18	15.00
Zaid Crop (RMC) – K	5.03	15.00	15.00	14.83	14.86	15.00	11.31
Area in Kharif (RMC)	62.86	187.52	187.52	187.30	187.33	127.27	183.77
Wheat (RMC) – R	75.42	225.03	114.27	114.90	114.61	182.04	142.43
Barley (RMC) – R	10.56	31.50	10.56	10.64	10.70	22.41	12.63
Gram (RMC) – R	63.36	189.03	189.03	182.59	186.45	99.90	146.95

(c) Table 6.21 presents release policy for hydropower generation for *PH 1* obtained by five solution techniques. It is observed that even though the monthly water releases obtained by various techniques are different, the annual releases obtained by LP, RGA and DE are similar whereas these are different for SA and SQ. Among SA and SQ, releases made by SQ are more.

(d) Table 6.22 presents annual surface water releases for LMC as obtained by five solution techniques. These are similar for LP, RGA and DE (around 351 Mm^3). In case of SA and SQ, these are 308.67 Mm^3 and 290.46 Mm^3 respectively.

(e) Table 6.23 presents annual surface water releases for RMC as obtained by five solution techniques. These are around 474 to 477 Mm^3 in case of LP, RGA, DE and SQ and 413.29 Mm^3 in case of SA.

(f) It is observed that the releases to RMC reaches its maximum capacity of 78.89 Mm^3 during February by LP, RGA, DE and SA.

(g) Table 6.24 presents annual surface water releases for Bhungra canal as obtained by five solution techniques. These are similar in case of LP, RGA and DE (around 27 Mm^3). These are 19.89 Mm^3, 22.75 Mm^3 in case of SA and SQ respectively.

6. Ground Water

Conjunctive use of water resources (in the form of ground water contribution) is not warranted due to the adequate amount of water in the reservoir.

7. Net Benefits

The values of net benefits are Rs.163.20 crores, Rs.162.22 crores, Rs.162.74 crores, Rs.140.31 crores and Rs.147.50 crores for LP, RGA, DE, SA and SQ respectively as observed from Table 6.19.

The above results are based on the optimal set of parameters obtained from Scenario 1. It is observed that careful selection of parameters is very important to come to a conclusion. This aspect is handled by extensive sensitivity analysis for Scenario 2 as discussed in section 6.4.3. Section 6.4.2 presents comparison of results obtained by ten DE strategies.

Crops	Crop area in '00 ha						
	Lower Limit	Upper Limit	LP	RGA	DE	SA	SQ
Barseen (RMC) – R	4.78	14.25	4.78	11.06	7.25	13.39	9.27
Mustard (RMC) – R	5.53	16.50	16.50	14.55	15.16	16.46	8.58
Fruits & Veg. (RMC) – R	1.26	3.75	3.75	3.71	3.70	3.34	1.31
Area in Rabi (RMC)	160.91	480.06	338.89	337.45	337.87	337.54	321.17
Total Area (Kharif+Rabi) (RMC)	223.77	667.58	526.41	524.75	525.20	464.81	504.94
Maize (BC) – K	0.36	1.05	1.05	1.03	1.04	0.36	0.37
Paddy (BC) – K	0.48	1.40	1.40	1.39	1.40	1.40	1.37
Cotton (BC) – K	1.08	3.14	3.14	3.14	3.13	2.45	3.06
Pulses (BC) – K	0.60	1.75	1.75	1.72	1.74	1.45	1.30
Sugarcane (BC) – K	0.24	0.70	0.70	0.69	0.69	0.28	0.44
Zaid Crop (BC) – K	0.24	0.70	0.70	0.54	0.65	0.54	0.67
Area in Kharif (BC)	3.00	8.74	8.74	8.51	8.65	6.48	7.21
Wheat (BC) – R	3.60	10.47	10.47	10.45	10.44	9.87	10.43
Barley (BC) – R	0.50	1.47	1.47	1.44	1.46	0.90	0.52
Gram (BC) – R	3.02	8.79	8.79	8.78	8.78	4.11	6.79
Barseen (BC) – R	0.23	0.66	0.66	0.66	0.64	0.58	0.25
Mustard (BC) – R	0.26	0.77	0.77	0.75	0.76	0.37	0.76
Fruits & Veg. (BC) – R	0.06	0.17	0.17	0.13	0.16	0.17	0.09
Area in Rabi (BC)	7.67	22.33	22.33	22.21	22.24	16.00	18.84
Total Area (Kharif+Rabi) (BC)	10.67	31.07	31.07	30.72	30.89	22.48	26.05
Total Area Kharif (LMC+RMC+BC)	143.85	308.76	308.76	307.72	308.38	242.78	284.26
Total Area Rabi (LMC+RMC+BC)	368.20	790.39	649.22	647.48	647.96	593.67	582.85
Total Area (Kharif+Rabi) (LMC+RMC+BC)	512.05	1099.15	957.98	955.20	956.34	836.45	867.11
Net Benefits (Rupees in Crores)			163.20	162.22	162.74	140.31	147.50

K-Kharif, R-Rabi, LMC-Left Main Canal, RMC-Right Main Canal, BC-Bhungra Canal

Table 6.20 Storage policy obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	1354.69	1354.71	1354.71	1356.00	1355.36
February	1014.97	1015.05	1015.04	1027.27	1028.42
March	749.98	750.10	750.10	774.97	777.08
April	578.29	578.42	578.41	603.60	605.59
May	419.52	419.65	419.64	444.88	446.85
June	262.87	263.00	262.99	288.40	290.31
July	124.14	124.31	124.28	157.13	154.99
August	20.53	20.80	20.72	69.69	56.60
September	498.66	498.99	498.88	568.84	540.76
October	1377.10 (212.72)*	1377.46 (213.09)*	1377.35 (212.98)*	1466.77 (302.82)*	1424.95 (260.77)*
November	2000.00	2000.00	2000.00	2000.00	2000.00
December	1678.71	1678.72	1678.72	1679.03	1678.85

*The value in braces denotes the overflows in Mm^3

Table 6.21 Release policy for hydropower generation in *PH 1* obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	219.66	219.63	219.63	210.07	207.69
February	227.46	227.43	227.42	216.25	214.64
March	143.36	143.36	143.36	143.36	143.36
April	126.37	126.37	126.37	126.37	126.37
May	116.81	116.81	116.81	116.81	116.81
June	121.78	121.76	121.77	114.66	118.63
July	152.64	152.58	152.60	137.04	147.88
August	169.20	169.16	169.17	148.85	163.68
September	164.42	164.40	164.40	145.56	159.10
October	195.13	195.13	195.13	195.13	195.13
November	203.09	203.09	203.09	203.09	203.09
December	206.41	206.41	206.41	206.41	206.41
Total	2046.33	2046.13	2046.16	1963.6	2002.79

Table 6.22 Release policy for irrigation for Left Main Canal obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	64.14	64.11	64.11	53.30	53.79
February	67.43	67.40	67.40	56.22	56.82
March	18.94	18.93	18.93	15.00	14.88
April	1.28	1.28	1.28	0.94	1.02
May	3.46	3.46	3.46	2.53	2.72
June	15.24	15.23	15.23	14.19	12.16
July	26.81	26.78	26.80	25.70	22.27
August	33.02	33.00	33.01	31.94	27.62
September	31.23	31.23	31.22	30.29	25.93
October	21.74	21.74	21.74	21.00	17.40
November	16.75	16.75	16.75	14.51	13.63
December	51.40	51.39	51.38	43.05	42.24
Total	351.44	351.31	351.31	308.67	290.46

Table 6.23 Release policy for irrigation for Right Main Canal obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	74.39	74.38	74.38	75.63	72.76
February	78.89	78.89	78.89	78.89	76.69
March	20.14	20.12	20.13	24.44	21.26
April	2.14	2.14	2.14	2.02	2.08
May	5.77	5.77	5.77	5.46	5.77
June	25.41	25.39	25.40	19.34	25.34
July	44.69	44.67	44.67	30.20	44.47
August	55.04	55.02	55.03	35.77	54.93
September	52.06	52.04	52.04	34.14	52.04
October	36.25	36.24	36.24	26.25	36.23
November	22.05	22.05	22.05	19.84	22.26
December	60.24	60.28	60.27	61.31	60.74
Total	477.07	476.99	477.00	413.29	474.58

Table 6.24 Release policy for irrigation for Bhungra Canal obtained by the five techniques (Mm^3)

Month	LP	RGA	DE	SA	SQ
January	4.97	4.95	4.96	3.58	4.17
February	5.23	5.21	5.21	3.74	4.38
March	1.47	1.46	1.46	1.14	1.27
April	0.10	0.10	0.10	0.04	0.06
May	0.27	0.27	0.27	0.11	0.17
June	1.18	1.17	1.18	0.83	0.92
July	2.08	2.05	2.07	1.53	1.62
August	2.56	2.53	2.55	1.88	2.04
September	2.42	2.40	2.41	1.78	1.99
October	1.69	1.68	1.68	1.26	1.50
November	1.30	1.29	1.29	0.98	1.17
December	3.99	3.97	3.97	2.99	3.45
Total	27.26	27.08	27.16	19.89	22.75

6.4.2 Comparison of Results Obtained by Ten DE Strategies for Scenario 2

Comparative analysis of results are made for ten DE strategies, namely, DE/rand/1/bin, DE/best/1/bin, DE/best/2/bin, DE/rand/2/bin, DE/rand-to-best/1/bin, DE/rand/1/exp, DE/best/1/exp, DE/best/2/exp, DE/rand/2/exp, DE/rand-to-best/1/exp. These are denoted as DE1 to DE10 respectively. These strategies were analyzed for NP=1100, CR=0.9, F=0.6 (optimum set of parameters obtained from Scenario 1). Table 6.25 presents the cropping pattern for LMC, RMC and BC, net benefits obtained for the chosen set (optimum set obtained from Scenario 1) of parameters for all ten DE strategies. It also includes the lower and upper limits for each variable. Table 6.26 presents the storage policy obtained by all ten DE strategies. Table 6.27 presents the release policy for hydropower generation in *PH 1*. Tables 6.28, 6.29, 6.30 present the release policy for irrigation for LMC, RMC and BC obtained by ten DE strategies. The following observations are made from the analysis of the results:

1. **Cropping Pattern (LMC)**

The percentage deviation of total area (both Kharif and Rabi) for DE1 to DE10 are 0.39, 0, 0.65, 0.53, 0.06, 0.34, 0.81, 0.99, 2.50 and 0.01 respectively from the upper limit. It is observed that the minimum and maximum deviations are zero in DE2 and 2.5 % in DE9 respectively.

2. **Cropping Pattern (RMC)**

The percentage deviation of total area (both Kharif and Rabi) from upper limit are 21.74, 21.15, 22.01, 21.40, 21.33, 21.60, 22.18, 22.52, 22.75 and 21.16 for DE1 to DE10 respectively. Minimum and maximum deviations from upper limit occurred for DE2 and DE9 strategies.

3. **Cropping Pattern (BC)**

The percentage deviation of total area (both Kharif and Rabi) are 4.89, 0, 3.28, 3.76, 0.58, 2.19, 2.99, 5.60, 18.86 and 0.23 for DE1 to DE10 respectively from the upper limit.

4. **Cropping Pattern (Total are of LMC+RMC+BC)**

In case of the total area scenario (both Kharif and Rabi), the ratio of total area to lower limit (in percentage) is 185.71, 187.09, 185.25, 186.11, 186.77, 186.10, 184.92, 184.18, 181.89 and 187.04 for DE1 to DE10 respectively.

5. **Reservoir Operation**

(a) It is observed from Table 6.26 that the storage values obtained by ten DE strategies are almost similar. It is observed that the reservoir reached its maximum capacity i.e., 2000 Mm^3 in the month of November for all ten DE strategies.

(b) No significant variation is observed for water releases for hydropower generation in *PH 1* for March to May and October to December. For the other months, slight variation is observed for ten DE strategies.

(c) Annual irrigation releases for LMC is maximum (351.44 Mm^3) for DE2 strategy and minimum (342.50 Mm^3) for DE9 strategy with a variation of 8.94 Mm^3.

(d) In case of RMC, annual irrigation releases are maximum (483.49 Mm^3) for DE9 strategy and minimum (470.83 Mm^3) for DE7 strategy with a variation of 12.66 Mm^3.

(e) In Bhungra Canal, annual irrigation releases are maximum (27.26 Mm^3) for DE2 strategy and minimum (20.87 Mm^3) for DE9 strategy with a variation of 6.39 Mm^3.

6. Ground Water

No ground water utilization is observed for all ten DE strategies as sufficient water is available from the reservoir.

7. Net Benefits

It is observed from Table 6.25 that net benefits vary from Rs.157.54 crores (DE9 strategy) to Rs.162.97 crores (DE10 strategy) with a range of Rs.5.43 crores.

1. **Cropping Pattern (LMC)**

The percentage deviation of total area (both Kharif and Rabi) for DE1 to DE10 are 0.39, 0, 0.65, 0.53, 0.06, 0.34, 0.81, 0.99, 2.50 and 0.01 respectively from the upper limit. It is observed that the minimum and maximum deviations are zero in DE2 and 2.5 % in DE9 respectively.

2. **Cropping Pattern (RMC)**

The percentage deviation of total area (both Kharif and Rabi) from upper limit are 21.74, 21.15, 22.01, 21.40, 21.33, 21.60, 22.18, 22.52, 22.75 and 21.16 for DE1 to DE10 respectively. Minimum and maximum deviations from upper limit occurred for DE2 and DE9 strategies.

3. **Cropping Pattern (BC)**

The percentage deviation of total area (both Kharif and Rabi) are 4.89, 0, 3.28, 3.76, 0.58, 2.19, 2.99, 5.60, 18.86 and 0.23 for DE1 to DE10 respectively from the upper limit.

4. **Cropping Pattern (Total are of LMC+RMC+BC)**

In case of the total area scenario (both Kharif and Rabi), the ratio of total area to lower limit (in percentage) is 185.71, 187.09, 185.25, 186.11, 186.77, 186.10, 184.92, 184.18, 181.89 and 187.04 for DE1 to DE10 respectively.

5. **Reservoir Operation**

(a) It is observed from Table 6.26 that the storage values obtained by ten DE strategies are almost similar. It is observed that the reservoir reached its maximum capacity i.e., 2000 Mm^3 in the month of November for all ten DE strategies.

(b) No significant variation is observed for water releases for hydropower generation in *PH 1* for March to May and October to December. For the other months, slight variation is observed for ten DE strategies.

1. **Cropping Pattern (LMC)**

The percentage deviation of total area (both Kharif and Rabi) for DE1 to DE10 are 0.39, 0, 0.65, 0.53, 0.06, 0.34, 0.81, 0.99, 2.50 and 0.01 respectively from the upper limit. It is observed that the minimum and maximum deviations are zero in DE2 and 2.5 % in DE9 respectively.

2. **Cropping Pattern (RMC)**

The percentage deviation of total area (both Kharif and Rabi) from upper limit are 21.74, 21.15, 22.01, 21.40, 21.33, 21.60, 22.18, 22.52, 22.75 and 21.16 for DE1 to DE10 respectively. Minimum and maximum deviations from upper limit occurred for DE2 and DE9 strategies.

3. **Cropping Pattern (BC)**

The percentage deviation of total area (both Kharif and Rabi) are 4.89, 0, 3.28, 3.76, 0.58, 2.19, 2.99, 5.60, 18.86 and 0.23 for DE1 to DE10 respectively from the upper limit.

4. **Cropping Pattern (Total are of LMC+RMC+BC)**

In case of the total area scenario (both Kharif and Rabi), the ratio of total area to lower limit (in percentage) is 185.71, 187.09, 185.25, 186.11, 186.77, 186.10, 184.92, 184.18, 181.89 and 187.04 for DE1 to DE10 respectively.

5. **Reservoir Operation**

(a) It is observed from Table 6.26 that the storage values obtained by ten DE strategies are almost similar. It is observed that the reservoir reached its maximum capacity i.e., 2000 Mm^3 in the month of November for all ten DE strategies.

(b) No significant variation is observed for water releases for hydropower generation in *PH 1* for March to May and October to December. For the other months, slight variation is observed for ten DE strategies.

(c) Annual irrigation releases for LMC is maximum (351.44 Mm^3) for DE2 strategy and minimum (342.50 Mm^3) for DE9 strategy with a variation of 8.94 Mm^3.

(d) In case of RMC, annual irrigation releases are maximum (483.49 Mm^3) for DE9 strategy and minimum (470.83 Mm^3) for DE7 strategy with a variation of 12.66 Mm^3.

(e) In Bhungra Canal, annual irrigation releases are maximum (27.26 Mm^3) for DE2 strategy and minimum (20.87 Mm^3) for DE9 strategy with a variation of 6.39 Mm^3.

6. Ground Water

No ground water utilization is observed for all ten DE strategies as sufficient water is available from the reservoir.

7. Net Benefits

It is observed from Table 6.25 that net benefits vary from Rs.157.54 crores (DE9 strategy) to Rs.162.97 crores (DE10 strategy) with a range of Rs.5.43 crores.

Table 6.25 Cropping pattern obtained by ten DE strategies

Crops	Crop Area ('00 ha)											
	Lower Limit	Upper Limit	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
Maize (LMC) – K	9.36	13.50	13.49	13.50	13.31	13.46	13.49	13.45	13.20	13.02	13.50	13.50
Paddy (LMC) – K	12.48	18.00	17.90	18.00	17.82	17.97	17.99	17.97	17.65	17.78	17.15	18.00
Cotton (LMC) – K	28.07	40.50	40.41	40.50	40.37	40.41	40.49	40.50	40.49	40.37	40.50	40.50
Pulses (LMC) – K	15.60	22.50	22.46	22.50	22.44	22.31	22.50	22.36	22.48	22.27	19.30	22.50
Sugarcane (LMC) – K	6.24	9.00	8.98	9.00	8.99	8.95	9.00	9.00	8.83	8.71	7.91	9.00
Zaid Crop (LMC) – K	6.24	9.00	8.80	9.00	8.36	8.30	8.93	8.32	9.00	8.89	7.53	8.98
Total Area (LMC) - K	77.99	112.50	112.04	112.50	111.29	111.40	112.40	111.60	111.65	111.04	105.89	112.48
Wheat (LMC) – R	93.57	135.00	134.96	135.00	134.83	134.95	134.96	134.95	134.56	134.16	135.00	135.00
Barley (LMC) – R	13.10	18.90	18.83	18.90	18.64	18.78	18.89	18.86	18.82	18.83	18.90	18.90
Gram (LMC) – R	78.60	113.40	113.34	113.40	113.20	113.39	113.37	113.36	112.50	113.13	113.40	113.40
Barseen (LMC) – R	5.93	8.55	8.51	8.55	8.26	8.40	8.52	8.52	8.51	8.37	7.85	8.55
Mustard (LMC) – R	6.86	9.90	9.21	9.90	9.48	9.34	9.87	9.69	8.98	9.40	7.45	9.89
Fruits & Veg. (LMC) – R	1.56	2.25	2.06	2.25	2.19	2.11	2.24	2.17	2.24	1.62	2.00	2.25
Total Area (LMC) - R	199.62	288.00	286.91	288.00	286.60	286.97	287.85	287.55	285.61	285.51	284.60	287.99
Total Area (LMC)	277.61	400.50	398.95	400.50	397.89	398.37	400.25	399.15	397.26	396.55	390.49	400.47
Maize (RMC) – K	7.54	22.50	22.43	22.50	22.17	22.46	22.50	22.47	19.90	22.31	22.50	22.50
Paddy (RMC) – K	10.06	30.00	29.93	30.00	29.91	30.00	30.00	29.94	29.99	28.84	30.00	30.00
Cotton (RMC) – K	22.63	67.51	67.51	67.51	67.43	67.43	67.49	67.45	67.38	67.26	67.51	67.51
Pulses (RMC) – K	12.57	37.51	37.49	37.51	37.47	37.44	37.49	37.43	37.13	37.40	37.51	37.50
Sugarcane (RMC) – K	5.03	15.00	14.96	15.00	14.94	14.99	14.99	14.95	13.97	13.82	15.00	15.00
Zaid Crop (RMC) – K	5.03	15.00	14.91	15.00	14.54	14.26	14.86	14.69	14.37	13.00	9.03	14.97
Total Area (RMC) - K	62.86	187.52	187.23	187.52	186.46	186.58	187.33	186.93	182.74	182.63	181.55	187.48
Wheat (RMC) – R	75.42	225.03	115.10	114.27	114.03	112.04	114.61	113.88	112.62	129.99	158.88	114.26
Barley (RMC) – R	10.56	31.50	12.83	10.56	15.14	14.20	10.70	13.56	29.86	19.38	16.20	10.64
Gram (RMC) – R	63.36	189.03	182.07	183.53	180.66	180.83	186.45	178.07	166.17	162.51	130.77	187.08
Barseen (RMC) – R	4.78	14.25	9.88	10.27	9.86	11.79	7.25	14.13	9.88	7.10	13.02	6.67
Mustard (RMC) – R	5.53	16.50	12.95	16.50	12.28	15.95	15.16	13.34	16.42	13.85	13.20	16.45

Crops	Crop Area ('00 ha)											
	Lower Limit	Upper Limit	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
Fruits & Veg. (RMC) – R	1.26	3.75	2.38	3.75	2.19	3.30	3.70	3.50	1.79	1.75	2.06	3.71
Total Area (RMC) - R	160.91	480.06	335.21	338.88	334.16	338.11	337.87	336.48	336.74	334.58	334.13	338.81
Total Area (RMC)	223.77	667.58	522.44	526.40	520.62	524.69	525.20	523.41	519.48	517.21	515.68	526.29
Maize (BC) – K	0.36	1.05	0.88	1.05	1.02	0.99	1.04	1.04	0.84	0.93	0.63	1.05
Paddy (BC) – K	0.48	1.40	1.35	1.40	1.36	1.32	1.40	1.38	1.34	1.37	0.60	1.40
Cotton (BC) – K	1.08	3.14	3.06	3.14	3.11	3.01	3.13	3.11	3.10	3.05	1.72	3.14
Pulses (BC) – K	0.60	1.75	1.63	1.75	1.64	1.64	1.74	1.73	1.68	1.66	1.27	1.74
Sugarcane (BC) – K	0.24	0.70	0.69	0.70	0.70	0.69	0.69	0.64	0.68	0.69	0.40	0.70
Zaid Crop (BC) – K	0.24	0.70	0.26	0.70	0.60	0.69	0.65	0.51	0.68	0.70	0.57	0.67
Total Area (BC) - K	3.00	8.74	7.87	8.74	8.43	8.34	8.65	8.41	8.32	8.40	5.19	8.70
Wheat (BC) – R	3.60	10.47	10.43	10.47	10.18	10.26	10.44	10.45	10.41	10.35	10.44	10.47
Barley (BC) – R	0.50	1.47	1.45	1.47	1.27	1.39	1.46	1.35	1.44	1.37	1.17	1.46
Gram (BC) – R	3.02	8.79	8.78	8.79	8.70	8.57	8.78	8.78	8.53	7.68	7.73	8.79
Barseen (BC) – R	0.23	0.66	0.39	0.66	0.66	0.58	0.64	0.51	0.60	0.61	0.26	0.66
Mustard (BC) – R	0.26	0.77	0.53	0.77	0.67	0.65	0.76	0.76	0.67	0.76	0.34	0.75
Fruits & Veg. (BC) – R	0.06	0.17	0.10	0.17	0.14	0.11	0.16	0.13	0.17	0.16	0.08	0.17
Total Area (BC) - R	7.67	22.33	21.68	22.33	21.62	21.56	22.24	21.98	21.82	20.93	20.02	22.30
Total Area (BC)	10.67	31.07	29.55	31.07	30.05	29.90	30.89	30.39	30.14	29.33	25.21	31.00
Total Area - K	143.85	308.76	307.14	308.76	306.18	306.32	308.38	306.94	302.71	302.07	292.63	308.66
Total Area - R	368.20	790.39	643.80	649.21	642.38	646.64	647.96	646.01	644.17	641.02	638.75	649.10
Total Area	512.05	1099.15	950.94	957.97	948.56	952.96	956.34	952.95	946.88	943.09	931.38	957.76
Net Benefits (Crores of Rupees)			161.67	162.61	161.09	161.42	162.74	161.29	158.87	159.61	157.54	162.97

K-Kharif, R-Rabi, LMC-Left Main Canal, RMC-Right Main Canal, BC-Bhungra Canal

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,

DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.26 Storage policy obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	1354.79	1354.69	1354.82	1354.85	1354.71	1354.77	1354.78	1354.94	1355.47	1354.69
February	1015.29	1014.97	1015.58	1015.40	1015.04	1015.17	1015.59	1015.94	1016.05	1014.98
March	750.54	749.98	751.11	750.72	750.10	750.32	751.49	752.05	752.11	750.00
April	578.88	578.29	579.47	579.07	578.41	578.66	579.82	580.41	580.56	578.31
May	420.10	419.52	420.69	420.30	419.64	419.90	421.05	421.64	421.83	419.53
June	263.46	262.87	264.05	263.65	262.99	263.27	264.41	264.99	265.30	262.89
July	124.89	124.14	125.56	125.07	124.28	124.68	126.80	127.41	128.12	124.16
August	21.58	20.53	22.42	21.80	20.72	21.33	24.90	25.36	27.44	20.56
September	500.02	498.66	501.04	500.28	498.88	499.71	504.91	505.05	508.57	498.69
October	1378.72 (214.40)*	1377.10 (212.72)*	1379.89 (215.54)*	1379.00 (214.70)*	1377.35 (212.98)*	1378.34 (213.99)*	1384.97 (220.65)*	1384.85 (220.53)*	1389.43 (225.84)*	1377.13 (212.76)*
November	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
December	1678.74	1678.71	1678.74	1678.75	1678.72	1678.73	1678.74	1678.77	1679.00	1678.71

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,

DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

*The value in braces denotes the overflows in Mm^3

Table 6.27 Release policy for hydropower generation in *PH 1* obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	219.54	219.66	219.34	219.54	219.63	219.63	219.23	219.24	219.85	219.66
February	227.32	227.46	227.08	227.30	227.42	227.40	226.68	226.68	226.92	227.45
March	143.36	143.36	143.36	143.36	143.36	143.36	143.36	143.36	143.36	143.36
April	126.37	126.37	126.37	126.37	126.37	126.37	126.37	126.37	126.37	126.37
May	116.81	116.81	116.81	116.81	116.81	116.81	116.81	116.81	116.81	116.81
June	121.69	121.78	121.57	121.68	121.77	121.68	120.73	120.67	120.76	121.78
July	152.48	152.64	152.24	152.40	152.60	152.43	151.04	151.17	150.59	152.63
August	169.04	169.20	168.78	168.97	169.17	169.00	167.46	167.74	167.27	169.20
September	164.28	164.42	164.06	164.25	164.40	164.27	162.91	163.16	163.04	164.42
October	195.13	195.13	195.13	195.13	195.13	195.13	195.13	195.13	195.13	195.13
November	203.09	203.09	203.09	203.09	203.09	203.09	203.09	203.09	203.09	203.09
December	206.41	206.41	206.41	206.41	206.41	206.41	206.41	206.41	206.41	206.41
Total	2045.52	2046.32	2044.23	2045.30	2046.16	2045.57	2039.22	2039.82	2039.60	2046.31

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,
DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.28 Release policy for irrigation for Left Main Canal obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	64.02	64.14	63.90	64.00	64.11	64.08	63.72	63.69	63.57	64.13
February	67.31	67.43	67.18	67.29	67.40	67.37	66.99	66.98	66.89	67.42
March	18.89	18.94	18.88	18.89	18.93	18.92	18.80	18.73	18.60	18.94
April	1.28	1.28	1.28	1.27	1.28	1.28	1.26	1.23	1.13	1.28
May	3.46	3.46	3.46	3.44	3.46	3.46	3.40	3.35	3.05	3.46
June	15.19	15.24	15.14	15.17	15.23	15.20	15.04	14.97	14.31	15.24
July	26.73	26.81	26.62	26.66	26.80	26.70	26.53	26.39	25.09	26.81
August	32.93	33.02	32.82	32.87	33.01	32.92	32.73	32.56	31.24	33.02
September	31.15	31.23	31.06	31.12	31.22	31.17	30.97	30.83	29.85	31.23
October	21.68	21.74	21.64	21.69	21.74	21.73	21.58	21.51	21.21	21.74
November	16.72	16.75	16.70	16.71	16.75	16.74	16.67	16.62	16.56	16.75
December	51.32	51.40	51.23	51.31	51.38	51.37	51.12	51.05	51.00	51.40
Total	350.68	351.44	349.91	350.42	351.31	350.94	348.81	347.91	342.50	351.42

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin, DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.29 Release policy for irrigation for Right Main Canal obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	74.38	74.39	74.30	74.40	74.38	74.41	74.38	74.41	75.14	74.39
February	78.87	78.89	78.77	78.87	78.89	78.89	78.55	78.56	78.89	78.89
March	20.10	20.14	20.09	20.11	20.13	20.13	20.49	20.98	22.81	20.14
April	2.10	2.14	2.09	2.13	2.14	2.13	1.95	1.93	2.10	2.14
May	5.76	5.77	5.75	5.77	5.77	5.75	5.38	5.32	5.77	5.77
June	25.36	25.41	25.29	25.37	25.40	25.35	24.55	24.57	25.32	25.40
July	44.62	44.69	44.49	44.60	44.67	44.59	43.37	43.64	44.37	44.69
August	54.97	55.04	54.83	54.96	55.03	54.94	53.59	54.05	54.90	55.04
September	52.00	52.06	51.87	52.00	52.04	51.97	50.80	51.20	52.06	52.06
October	36.21	36.25	36.14	36.21	36.24	36.19	35.61	35.53	36.25	36.24
November	22.01	22.05	21.94	21.96	22.05	21.99	21.69	22.05	22.84	22.05
December	60.33	60.24	60.28	60.21	60.27	60.31	60.47	61.11	63.04	60.24
Total	476.71	477.07	475.84	476.59	477.01	476.65	470.83	473.35	483.49	477.05

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin, DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

Table 6.30 Release policy for irrigation for Bhungra Canal obtained by ten DE strategies (Mm^3)

Month	DE1	DE2	DE3	DE4	DE5	DE6	DE7	DE8	DE9	DE10
January	4.88	4.97	4.83	4.83	4.96	4.89	4.87	4.68	4.49	4.97
February	5.13	5.23	5.08	5.08	5.21	5.14	5.12	4.91	4.72	5.23
March	1.44	1.47	1.42	1.43	1.46	1.44	1.44	1.42	1.32	1.47
April	0.1	0.1	0.1	0.1	0.1	0.09	0.1	0.1	0.06	0.1
May	0.26	0.27	0.27	0.27	0.27	0.25	0.26	0.27	0.15	0.27
June	1.12	1.18	1.15	1.13	1.18	1.15	1.12	1.14	0.65	1.18
July	1.94	2.08	2.01	1.98	2.07	2.03	1.96	1.99	1.21	2.08
August	2.41	2.56	2.49	2.44	2.55	2.51	2.42	2.45	1.48	2.56
September	2.3	2.42	2.36	2.31	2.41	2.38	2.3	2.32	1.38	2.42
October	1.63	1.69	1.66	1.62	1.68	1.65	1.63	1.63	0.9	1.69
November	1.27	1.3	1.27	1.26	1.29	1.28	1.28	1.25	1.02	1.3
December	3.91	3.99	3.88	3.87	3.97	3.92	3.92	3.79	3.49	3.98
Total	26.39	27.26	26.52	26.32	27.15	26.73	26.42	25.95	20.87	27.25

DE1- DE/rand/1/bin, DE2- DE/best/1/bin, DE3 - DE/best/2/bin, DE4 - DE/rand/2/bin, DE5 - DE/rand-to-best/1/bin,
DE6 - DE/rand/1/exp, DE7 - DE/best/1/exp, DE8 - DE/best/2/exp, DE9 - DE/rand/2/exp, DE10 - DE/rand-to-best/1/exp

It is observed from Table 6.31 that the number of generations 3000, population size of 1100, crossover probability of 0.85, distribution index of 2 for SBX, mutation probability of 0.01, distribution index of 100 for mutation is identified as the optimal set of parameters for RGA. The optimal set of parameters for DE are the number of generations 3000, population size of 1200, crossover constant of 0.8, weighting factor of 0.5 for DE/best/1/bin strategy. In case of SA, the number of iterations 130, initial temperature of 900, final temperature of 0.1, cooling rate of 0.90 are the optimal set of parameters. The optimal set of parameters for SQ are the number of iterations 110, initial temperature of 500, final temperature of 0.1, cooling rate of 0.90.

6.4.4.2 Comparison of Results Obtained by Five Solution Techniques for Optimal Set of Parameters (Scenario 2)

Results obtained by RGA, DE, SA and SQ for optimal set of parameters are compared with that of LP. It is observed that RGA, DE, SA and SQ produced the same results as that of LP. Table 6.32 presents the cropping pattern, Table 6.33 presents the release policy for irrigation for LMC, RMC, BC, Fig. 6.105 presents the monthly storage policy values (including that of overflow) whereas Fig. 6.106 presents the release policy for hydropower in *PH 1*. The following observations are made from the analysis of the results:

1. **Cropping Pattern (LMC)**

   It is observed from Table 6.32 that for Kharif and Rabi seasons, all the crops have reached their upper limit. The ratio of total area to lower limit (in percentage) in LMC is 144.27.

2. **Cropping Pattern (RMC)**

   It is observed in Kharif season that all the crops have reached the upper limit. But, in case of Rabi season, 33889 ha are irrigated out of the available 48006 ha. This is because irrigation requirements in the month of February are more than the available canal capacity. In this regard, water required for irrigation cannot be supplied even though sufficient water is available in the reservoir.

6.4.3 Sensitivity Analysis

The same settings which were employed in Scenario 1 are used in RGA, DE, SA and SQ. The parameters used in each technique is varied the same way as mentioned in Scenario 1 and the total number of combinations for RGA, DE, SA and SQ are 594, 3600, 726 and 726 respectively. Variation in each parameter is studied for all four non-traditional optimization techniques. The graphs for the variation of parameters and inferences are not presented here due to their similarity in nature as compared to Scenario 1.

6.4.4 An Overview for Scenario 2

6.4.4.1 Optimal Parameters for Various Non-traditional Optimization Techniques

The optimal set of parameters obtained after analyzing 594, 3600, 726 and 726 combinations for RGA, DE, SA and SQ are presented in Table 6.31.

Table 6.31 Optimal set of parameters for four non-traditional optimization techniques

Optimization Technique	Number of Combinations	Optimal Set of Parameters
Real-coded Genetic Algorithms (RGA)	594 (POP-11 levels, XR-9 levels and MUT-6 levels)	Generations = 3000 Population Size POP = 1000 Crossover Probability XR = 0.85 Distribution index for SBX = 2 Mutation Probability MUT = 0.01 Distribution index for parameter based mutation = 100
Differential Evolution (DE)	3600 (NP-10 levels, CR-6 levels, F-6 levels and 10 strategies)	Generations = 3000 Population Size NP = 1200 Crossover Constant CR = 0.8 Weighting Factor F = 0.5 Strategy = DE/best/1/bin
Simulated Annealing (SA)	726 (NI-11 levels, T-11 levels and CoR-6 levels)	Number of Iterations NI = 130 Initial Temperature T = 900 Final Temperature=0.1 Cooling Rate CoR = 0.90
Simulated Quenching (SQ)	726 (NI''-11 levels, T''-11 levels and CoR''-6 levels)	Number of Iterations $NI'' = 110$ Initial Temperature $T'' = 500$ Final Temperature=0.1 Cooling Rate $CoR'' = 0.90$

It is observed from Table 6.31 that the number of generations 3000, population size of 1100, crossover probability of 0.85, distribution index of 2 for SBX, mutation probability of 0.01, distribution index of 100 for mutation is identified as the optimal set of parameters for RGA. The optimal set of parameters for DE are the number of generations 3000, population size of 1200, crossover constant of 0.8, weighting factor of 0.5 for DE/best/1/bin strategy. In case of SA, the number of iterations 130, initial temperature of 900, final temperature of 0.1, cooling rate of 0.90 are the optimal set of parameters. The optimal set of parameters for SQ are the number of iterations 110, initial temperature of 500, final temperature of 0.1, cooling rate of 0.90.

6.4.4.2 Comparison of Results Obtained by Five Solution Techniques for Optimal Set of Parameters (Scenario 2)

Results obtained by RGA, DE, SA and SQ for optimal set of parameters are compared with that of LP. It is observed that RGA, DE, SA and SQ produced the same results as that of LP. Table 6.32 presents the cropping pattern, Table 6.33 presents the release policy for irrigation for LMC, RMC, BC, Fig. 6.105 presents the monthly storage policy values (including that of overflow) whereas Fig. 6.106 presents the release policy for hydropower in *PH 1*. The following observations are made from the analysis of the results:

1. **Cropping Pattern (LMC)**

   It is observed from Table 6.32 that for Kharif and Rabi seasons, all the crops have reached their upper limit. The ratio of total area to lower limit (in percentage) in LMC is 144.27.

2. **Cropping Pattern (RMC)**

   It is observed in Kharif season that all the crops have reached the upper limit. But, in case of Rabi season, 33889 ha are irrigated out of the available 48006 ha. This is because irrigation requirements in the month of February are more than the available canal capacity. In this regard, water required for irrigation cannot be supplied even though sufficient water is available in the reservoir.

3. **Cropping Pattern (BC)**

In this case, all the crops have reached their upper limit.

4. **Cropping Pattern (Total area of LMC+RMC+BC) and Net Benefits**

(a) The total area irrigated is 95798 ha and maximum net benefits from the project is Rs.163.20 crores.

(b) The ratio of total area to lower limit (in percentage) is 187.09. It is also observed that net benefits per ha is Rs.17035.85 ≅ Rs.17036.

5. **Reservoir Operation**

(a) It is observed from Fig. 6.105 that maximum live storage reached in the month of November and correspondingly the overflows are 212.72 Mm^3.

(b) It is observed from Table 6.33 that irrigation releases for LMC, RMC, BC are high during the months January, February and December whereas it is very low during the months of April and May.

(c) The annual releases (surface water) for LMC, RMC and BC are 351.44 Mm^3, 477.07 Mm^3 and 27.26 Mm^3.

(d) It is observed from Fig. 6.106 that releases to *PH 1* vary from 116.12 Mm^3 to 227.46 Mm^3.

6. **Ground Water**

No ground water utilization is observed as sufficient water is available from the reservoir for irrigation.

Table 6.32 Cropping pattern obtained by the five techniques with optimal set of parameters for Scenario 2

Crops	Crop area in '00 ha			Percentage deviation from Upper Limit (%)
	Lower Limit	Upper Limit	Crop Area	
Maize (LMC) – K	9.36	13.50	13.50	0.00
Paddy (LMC) – K	12.48	18.00	18.00	0.00
Cotton (LMC) – K	28.07	40.50	40.50	0.00
Pulses (LMC) – K	15.60	22.50	22.50	0.00
Sugarcane (LMC) – K	6.24	9.00	9.00	0.00
Zaid Crop (LMC) – K	6.24	9.00	9.00	0.00
Area in Kharif (LMC)	77.99	112.50	112.50	0.00
Wheat (LMC) – R	93.57	135.00	135.00	0.00
Barley (LMC) – R	13.10	18.90	18.90	0.00
Gram (LMC) – R	78.60	113.40	113.40	0.00
Barseen (LMC) – R	5.93	8.55	8.55	0.00
Mustard (LMC) – R	6.86	9.90	9.90	0.00
Fruits & Veg. (LMC) – R	1.56	2.25	2.25	0.00
Area in Rabi (LMC)	199.62	288.00	288.00	0.00
Total Area (Kharif+Rabi) (LMC)	277.61	400.50	400.50	0.00
Ratio of Total Area to Lower Limit (LMC) (%)			144.27	-
Maize (RMC) – K	7.54	22.50	22.50	0.00
Paddy (RMC) – K	10.06	30.00	30.00	0.00
Cotton (RMC) – K	22.63	67.51	67.51	0.00
Pulses (RMC) – K	12.57	37.51	37.51	0.00
Sugarcane (RMC) – K	5.03	15.00	15.00	0.00
Zaid Crop (RMC) – K	5.03	15.00	15.00	0.00
Area in Kharif (RMC)	62.86	187.52	187.52	0.00
Wheat (RMC) – R	75.42	225.03	114.27	49.22
Barley (RMC) – R	10.56	31.50	10.56	66.48
Gram (RMC) – R	63.36	189.03	189.03	0.00
Barseen (RMC) – R	4.78	14.25	4.78	66.46
Mustard (RMC) – R	5.53	16.50	16.50	0.00
Fruits & Veg. (RMC) – R	1.26	3.75	3.75	0.00
Area in Rabi (RMC)	160.91	480.06	338.89	29.41
Total Area (Kharif+Rabi) (RMC)	223.77	667.58	526.41	21.15
Ratio of Total Area to Lower Limit (RMC) (%)			235.25	-
Maize (BC) – K	0.36	1.05	1.05	0.00
Paddy (BC) – K	0.48	1.40	1.40	0.00
Cotton (BC) – K	1.08	3.14	3.14	0.00
Pulses (BC) – K	0.60	1.75	1.75	0.00
Sugarcane (BC) – K	0.24	0.70	0.70	0.00

Crops	Crop area in '00 ha			Percentage deviation from Upper Limit (%)
	Lower Limit	Upper Limit	Crop Area	
Zaid Crop (BC) – K	0.24	0.70	0.70	0.00
Area in Kharif (BC)	3.00	8.74	8.74	0.00
Wheat (BC) – R	3.60	10.47	10.47	0.00
Barley (BC) – R	0.50	1.47	1.47	0.00
Gram (BC) – R	3.02	8.79	8.79	0.00
Barseen (BC) – R	0.23	0.66	0.66	0.00
Mustard (BC) – R	0.26	0.77	0.77	0.00
Fruits & Veg. (BC) – R	0.06	0.17	0.17	0.00
Area in Rabi (BC)	7.67	22.33	22.33	0.00
Total Area (Kharif+Rabi) (BC)	10.67	31.07	31.07	0.00
Ratio of Total Area to Lower Limit (BC) (%)			291.19	-
Total Area (Kharif) (LMC+RMC+BC)	143.85	308.76	308.76	0.00
Total Area (Rabi) (LMC+RMC+BC)	368.20	790.39	649.22	17.86
Total Area (Kharif+Rabi) (LMC+RMC+BC)	512.05	1099.15	957.98	12.84
Ratio of Total Area to Lower Limit (LMC+RMC+BC) (%)			187.09	-

K-Kharif, R-Rabi, LMC-Left Main Canal, RMC-Right Main Canal, BC-Bhungra Canal

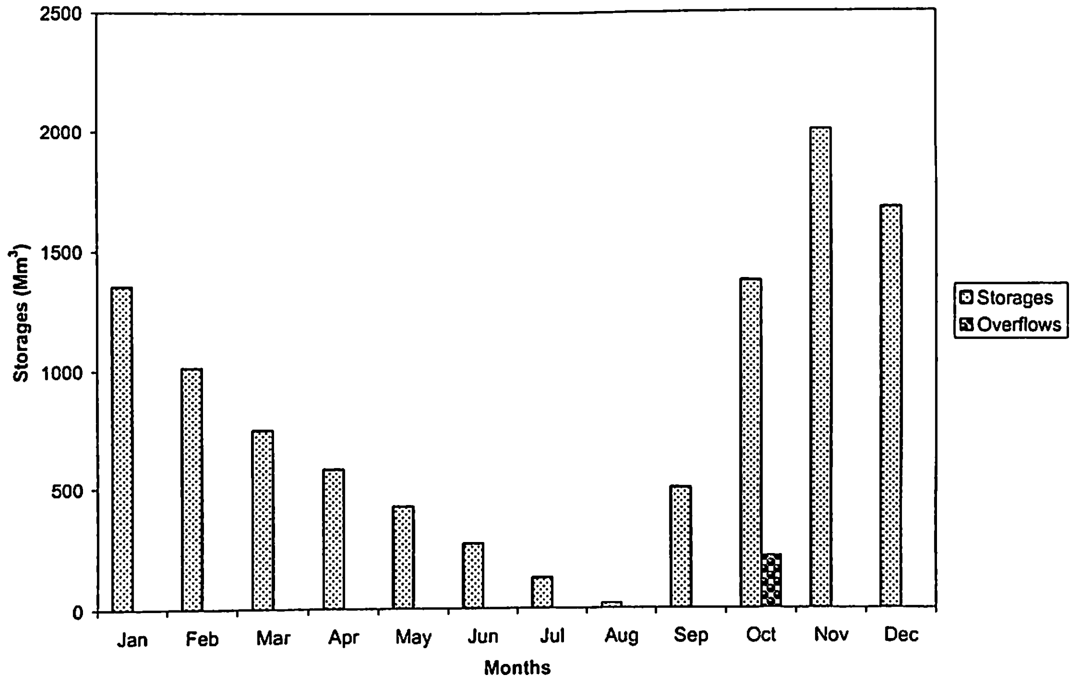

Fig. 6.105 Monthly storages and overflows obtained by the five techniques with optimal set of parameters for Scenario 2 (Mm^3)

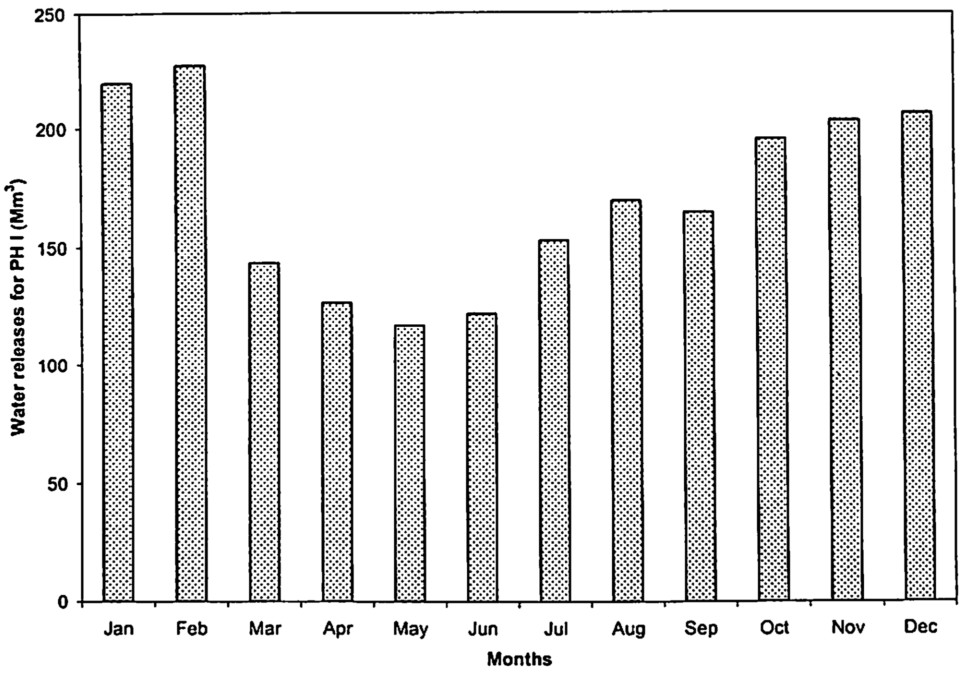

Fig. 6.106 Release policy for hydropower generation in *PH 1* obtained by the five techniques with optimal set of parameters for Scenario 2 (Mm^3)

Table 6.33 Release policy for irrigation for LMC, RMC and BC obtained by the five techniques with optimal set of parameters for Scenario 2 (Mm^3)

Month	LMC	RMC	BC
January	64.14	74.39	4.97
February	67.43	78.89	5.23
March	18.94	20.14	1.47
April	1.28	2.14	0.1
May	3.46	5.77	0.27
June	15.24	25.41	1.18
July	26.81	44.69	2.08
August	33.02	55.04	2.56
September	31.23	52.06	2.42
October	21.74	36.25	1.69
November	16.75	22.05	1.3
December	51.4	60.24	3.99
Total	351.44	477.07	27.26

LMC-Left Main Canal, RMC-Right Main Canal,
BC-Bhungra Canal, SW-Surface Water

6.4.5 Comparative Analysis of Scenario 1 and Scenario 2

6.4.5.1 Irrigation Planning Aspects

Comparative analysis is made for Scenario 1 and Scenario 2 and presented in Table 6.34. The following observations are made from the study:

- It is observed that the total area of crops irrigated in MBSP has increased from 67736 ha (Scenario 1) to 95798 ha (Scenario 2) with corresponding increase of net benefits from Rs.113.15 crores to Rs.163.20 crores.
- Increase of benefits in Scenario 2 may be attributed to the increase in crop area by 41.43 % and availability of more water in the reservoir by 9.33 % due to reduction in overflows by 49.76 %.
- Ground water withdrawal is not required for Scenario 2 due to additional available water in the reservoir. This reduces the burden on the dwindling ground water resources to a greater extent which is a boon to drought prone state like Rajasthan.
- Net benefits ha for Scenario 2 is 2 % more than that of Scenario 1.

6.4.5.2 Comparison of Optimal Set of Parameters

Comparative analysis of optimal set of parameters that are obtained by extensive

6.4.5 Comparative Analysis of Scenario 1 and Scenario 2

6.4.5.1 Irrigation Planning Aspects

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- Ground water withdrawal is not required for Scenario 2 due to additional available water in the reservoir. This reduces the burden on the dwindling ground water resources to a greater extent which is a boon to drought prone state like Rajasthan.
- Net benefits/ha for Scenario 2 is 2 % more than that of Scenario 1.

6.4.5.2 Comparison of Optimal Set of Parameters

Comparative analysis of optimal set of parameters that are obtained by extensive sensitivity analysis for Scenario 1 and Scenario 2 (presented in Table 6.16 and Table 6.31) reveals that:

- The optimal set of parameters obtained for Scenario 1 and Scenario 2 are very close to each other.
- High cross over probability values of 0.90, 0.85 and low mutation probability values of 0, 0.01 (obtained as optimal in RGA studies), high value of crossover constant of 0.9, 0.8 and low weighting factor values of 0.5 and 0.6 (obtained as optimal in DE studies) and high cooling rates of 0.90 and 0.85 (obtained as optimal in SA and SQ studies) supports the literature as explained in Section 6.2.1.

Table 6.34 Comparison of results from Scenario 1 and Scenario 2

	Results from Scenario 1 using optimal set of parameters	Results from Scenario 2 using optimal set of parameters	Percentage Increase
Total Area (Kharif+Rabi) (LMC)	35068 ha	40050 ha	14.21
Total Area (Kharif+Rabi) (RMC)	30790 ha	52641 ha	70.97
Total Area (Kharif+Rabi) (BC)	1878 ha	3107 ha	65.44
Total Area (Kharif+Rabi) (LMC+RMC+BC)	67736 ha	95798 ha	41.43
Maximum Live Storage	1829.27 Mm^3	2000 Mm^3	9.33
Overflows Observed	423.40 Mm^3	212.72 Mm^3	-49.76
Annual Releases (LMC)	303.65 Mm^3	351.44 Mm^3	15.74
Annual Releases (RMC)	265.50 Mm^3	477.07 Mm^3	79.69
Annual Releases (BC)	15.63 Mm^3	27.26 Mm^3	74.41
Ground Water Withdrawal	31.07 Mm^3	0 Mm^3	-100
Net Benefits	Rs.113.15 crores	Rs.163.20 crores	44.23
Net Benefits/Total Area	Rs.16705 per ha	Rs.17036 per ha	1.98

The next section discusses the results of performance evaluation studies presented as Part 2. It includes application of KANN and MCDM techniques. Extensive sensitivity analysis is also made to ascertain the effect of various parameters on the ranking pattern.

PART 2: PERFORMANCE EVALUATION STUDIES

6.5 ANALYSIS OF RESULTS (PART 2)

Part 2 deals with performance evaluation studies of sixteen irrigation subsystems of Mahi Bajaj Sagar Project with the objective of selecting the suitable irrigation subsystem. In the present study, a three phase methodology is proposed to rank the irrigation subsystems. In the first phase, payoff matrix for sixteen irrigation subsystems is formulated as explained in Section 5.9. Seven performance criteria, namely, Land Development Works (LDW), Timely Supply of Inputs (TSI), Conjunctive Use of Water resources (CUW), Participation of Farmers' (PF), Economic Impact (EI), Crop PRoductivity (CPR) and Environmental Conservation (EC) are considered for evaluation. In the second phase, Kohonen Artificial Neural Networks (KANN) based classification algorithm is employed to classify the irrigation subsystems into smaller groups. In the third and final phase, three Multicriterion decision making (MCDM) techniques, namely, Multicriterion Q-Analysis-2 (MCQA-2), Multi Attribute Utility Theory (MAUT) and Compromise Programming (CP) are employed to rank the groups obtained from the second phase. Extensive sensitivity analysis studies are also made on all the techniques for various parameters to check the robustness in ranking. The results obtained from the above three phase methodology are discussed below.

6.5.1 Phase 1: Formulation of Payoff Matrix

Phase 1: In this section payoff matrix formulated by the procedure as explained in Section 5.9 is presented in Table 6.35 (a) which is same as Table 5.9 (reproduced here for further analysis).

6.5.2 Phase 2: Classification of Irrigation Subsystems using Kohonen Artificial Neural Networks

Kohonen Artificial Neural Networks (KANN) methodology is used to classify the irrigation subsystems using neural network tool box of MATLAB (http://www.mathworks.com/products/neuralnet/index.html). An interactive coding is developed in MATLAB neural network environment using existing built-in functions such as NEWC, NET, TRAIN and SIM as per methodology explained in Section 4.5. These functions are used for creating, training and simulating the networks and thereby classifying the input data sets (in this case sixteen irrigation subsystems). Fig. 6.107 presents schematic diagram of KANN for the present planning problem. Input layer consists of seven performance criteria (representing 1 to 7), namely, LDW, TSI, CUW, PF, EI, CPR and EC whereas output layer is Kohonen layer consists of a number of groups (representing with G1 to G8 as chosen in the present planning problem). Weights of the criteria estimated by AHP methodology are used here for further analysis. These are 0.0362, 0.0881, 0.1179, 0.1171, 0.3554, 0.1928 and 0.0925 for LDW, TSI, CUW, PF, EI, CPR and EC respectively (Section 5.8).

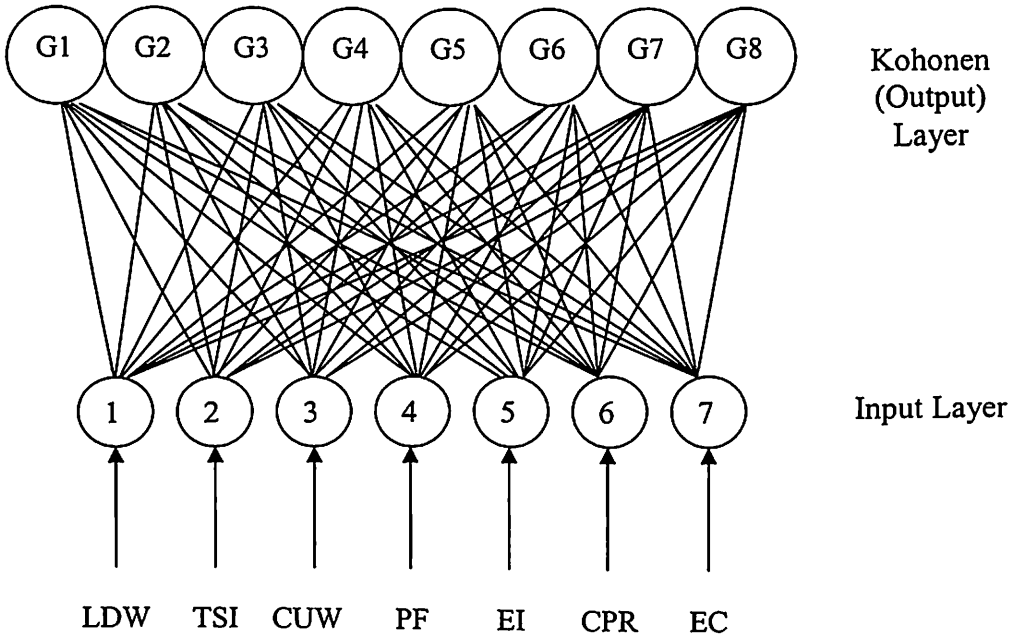


Fig. 6.107 Schematic diagram of KANN methodology for classification of irrigation subsystems

For the network to operate properly, the input vector must be normalized (to make it dimensionless) to ensure that the Kohonen layer finds the correct class for the problem. In the present case, payoff matrix formulated is already a normalized matrix (as it is based on a numerical scale of 0 to 100). Weighted normalized payoff matrix is prepared (i.e., weights of the criteria are multiplied with payoff matrix values of concerned criteria) to consider views of the decision maker and presented in Table 6.35 (b).

Table 6.35 (a) Normalized payoff matrix

Irrigation subsystems	LDW	TSI	CUW	PF	EI	CPR	EC
IS1	36	75	39	66	43	45	64
IS2	37	52	46	54	42	53	59
IS3	22	82	26	47	57	54	69
IS4	41	41	56	56	64	57	77
IS5	64	49	47	47	50	51	65
IS6	46	85	33	69	49	67	55
IS7	67	84	44	38	51	32	36
IS8	53	77	52	58	64	49	68
IS9	45	65	47	78	54	46	46
IS10	37	59	36	65	58	59	69
IS11	49	79	56	61	39	64	61
IS12	54	79	49	70	62	60	47
IS13	49	56	27	33	48	42	71
IS14	53	66	46	27	41	50	72
IS15	34	59	46	49	47	59	37
IS16	27	63	31	57	51	27	48

The parameters used for the study are number of groups (4, 5, 6, 7, 8), different epochs (5000, 10000, 20000, 30000, 40000, 50000), various learning rates (0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0) and conscience rate (kept constant as 0.001). This result in 450 combinations (5 groups, 6 epochs and 15 learning rates). The program is run for 450 combinations to see their effect on square error (square of euclidean distance) values. This also enables to determine the appropriate parameters for the present planning problem (http://www.mathworks.com/products/neuralnet/index.html). Here group 4 indicates that the input data are classified into 4 groups.

Table 6.35 (b) Weighted normalized payoff matrix and representative group from Kohonen classification

Irrigation subsystems	LDW	TSI	CUW	PF	EI	CPR	EC	Groups	Square Error
IS1	1.3043	6.6060	4.5977	7.7306	15.2813	8.6765	5.9187	**G8****	2.3680
IS2	1.3405	4.5802	5.4229	6.3250	14.9260	10.2189	5.4563	G8	2.3725
IS3	0.7971	7.2226	3.0651	5.5051	20.2567	10.4117	6.3811	**G3****	2.8198
IS4	1.4854	3.6113	6.6018	6.5593	22.7443	10.9902	7.1210	**G5****	3.3983
IS5	2.3187	4.3159	5.5408	5.5051	17.769	9.8333	6.0112	G2	3.0622
IS6	1.6666	7.4868	3.8904	8.0820	17.4136	12.9183	5.0864	G7	5.4513
IS7	2.4274	7.3987	5.1872	4.4509	18.1244	6.1699	3.3293	G1	3.7481
IS8	1.9202	6.7822	6.1303	6.7935	22.7443	9.4477	6.2886	G5	3.3983
IS9	1.6304	5.7252	5.5408	9.1361	19.1905	8.8693	4.2541	**G4****	4.4751
IS10	1.3405	5.1967	4.2440	7.6135	20.6120	11.3758	6.3811	G3	2.8254
IS11	1.7753	6.9583	6.6018	7.1449	13.8598	12.3398	5.6413	**G7****	5.4452
IS12	1.9564	6.9583	5.7766	8.1991	22.0336	11.5686	4.3466	G4	4.4941
IS13	1.7753	4.9325	3.1830	3.8653	17.0582	8.0980	6.5661	**G6****	3.7196
IS14	1.9202	5.8133	5.4229	3.1625	14.5706	9.6405	6.6586	G6	3.7224
IS15	1.2318	5.1967	5.4229	5.7394	16.7029	11.3758	3.4218	**G2****	3.0613
IS16	0.9782	5.5490	3.6546	6.6764	18.1244	5.2059	4.4390	**G1****	3.7439
								Total	58.1055

** Representative Irrigation subsystem for the corresponding group

Fig. 6.108 presents the effect of learning rate(s) on square error values for different epochs for group 4. It is observed from Fig. 6.108 that variation of square error is in the range of 18.1063 i.e., minimum of 114.0709 for learning rate of 0.05 and maximum of 132.1772 for learning rate of 0.08. From learning rate of 0.2 onwards, a steep error variation is observed from 120.2662 to 237.7602. For group 5 (Fig. 6.109), the square error variation is approximately in between 100 to 200. Slight variation of error is also observed for each learning rate for various epochs. This is more significant for learning rate beyond 0.4. A similar trend is observed for group 6 (Fig. 6.110), group 7 (Fig. 6.111) and group 8 (Fig. 6.112). The range of square error for group 6 is minimum of 82.7379 for learning rate of 0.2, maximum of 184.9536 for learning rate 1.0, that of group 7 is minimum of 70.2509 for learning rate 0.2, maximum of 150.8512 for learning rate 1.0, and that of group 8 is minimum of 58.1055 for learning rate of 0.01, maximum of 117.6208 for learning rate of 1.0 as observed from above graphs.

In the present study, learning rate of 0.01 and conscience rate of 0.001 are used as supported by literature (http://www.mathworks.com/products/neuralnet/index.html). Fig. 6.113 (a) presents the variation of square error values for various groups and different epochs for a learning rate of 0.01 and conscience rate of 0.001. It is observed from Fig. 6.113 (a) that square error value is decreasing from group 4 (123.8332 for 20000 and 50000 epochs, 126.3457 for 30000 epochs) to group 8 (58.1055 for 30000 epochs, 68.2792 for 40000 epochs). The range of square error values for group 5 is minimum of 106.2387, maximum of 112.7081, that of group 6 is minimum of 89.0174, maximum of 100.9635 and that of group 7 is minimum of 74.6149, maximum of 95.4666. It is also observed that maximum and minimum square error values are reducing simultaneously with the increase in number of groups from 4 to 8 as shown in Fig. 6.113 (b). It is inferred from the above analysis that effect of learning rates, epochs is having significant effect on square error values.

The maximum number of groups is fixed as 8, as proper classification did not occur for groups more than 8 and it was not found relevant to classify beyond 8 as the maximum number of irrigation subsystems are 16. Keeping the above parameters in view (learning rate 0.01, conscience rate of 0.001 and group 8), the number of epochs is fixed as 30000. With this combination, the minimum square value is 58.1055 as evident from Fig 6.113 (a). Table 6.36 presents the weights of the groups obtained by KANN methodology for the above combination (as explained in Section 4.5). These parameters can be used further for the simulating the network, if more data are available for classification.

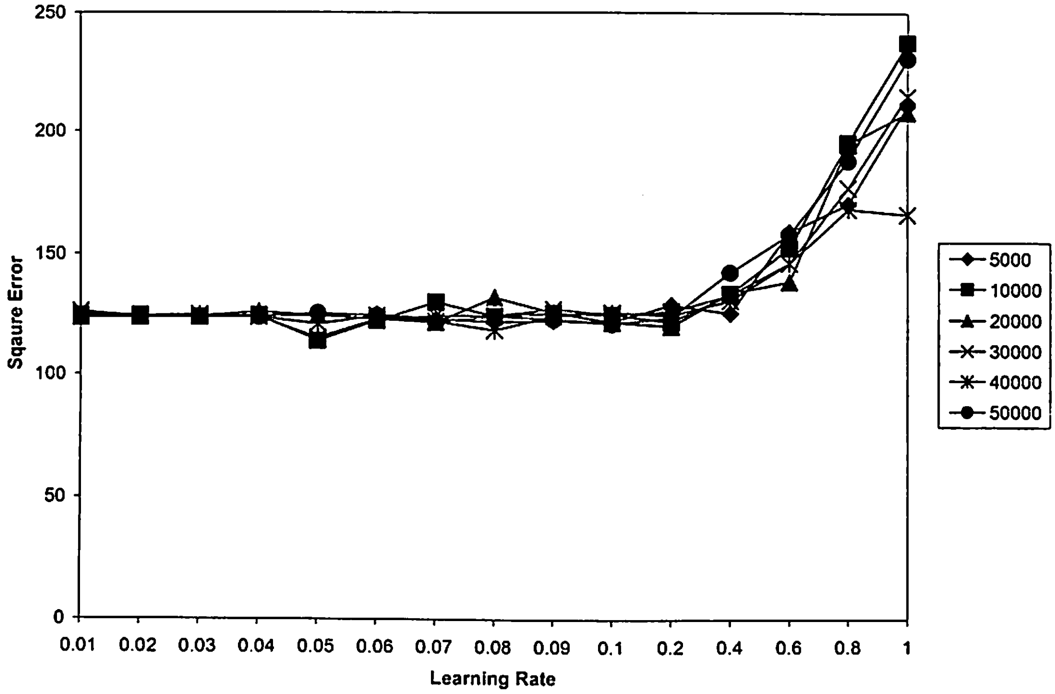


Fig. 6.108 Variation of square error value for various learning rates and epochs (Conscience rate = 0.001 and Group 4)

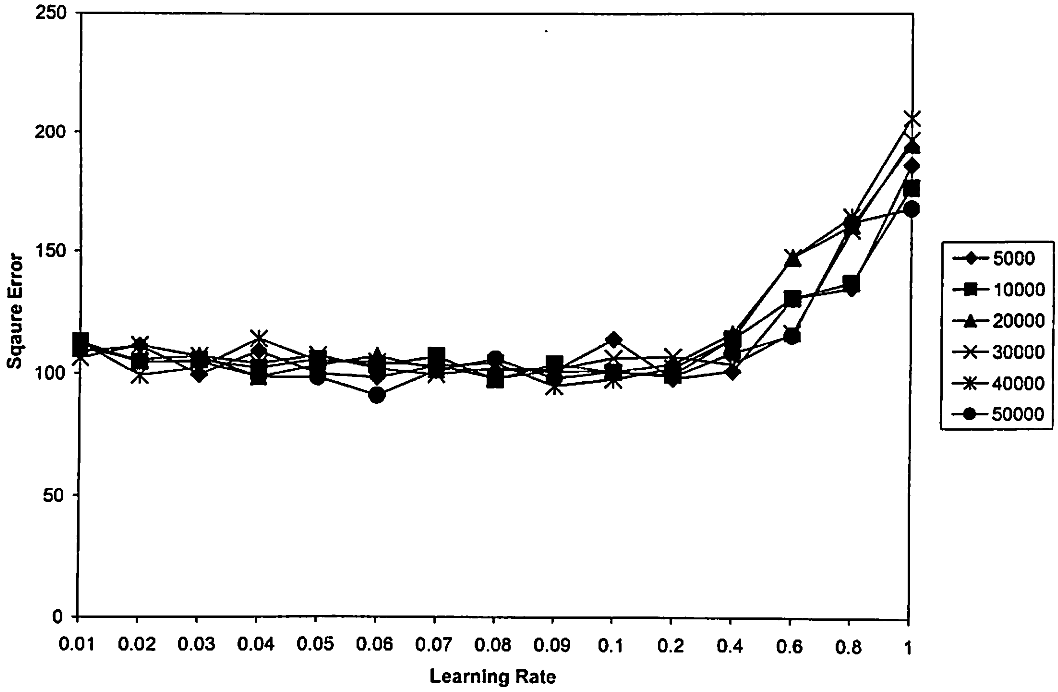


Fig. 6.109 Variation of square error value for various learning rates and epochs (Conscience rate = 0.001 and Group 5)

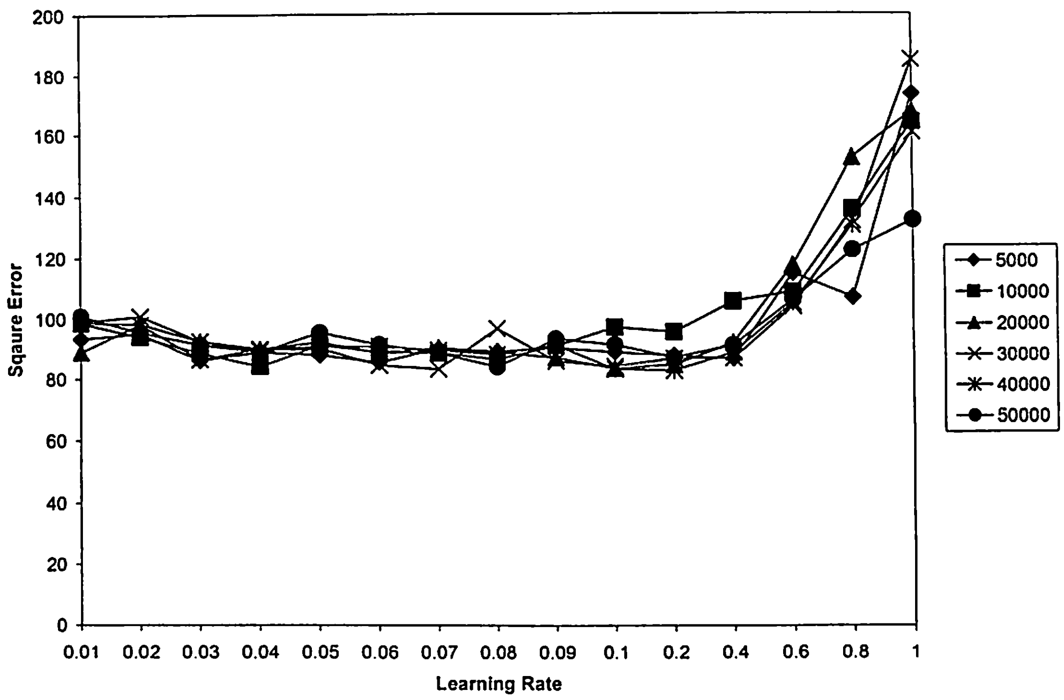


Fig. 6.110 Variation of square error value for various learning rates and epochs (Conscience rate = 0.001 and Group 6)

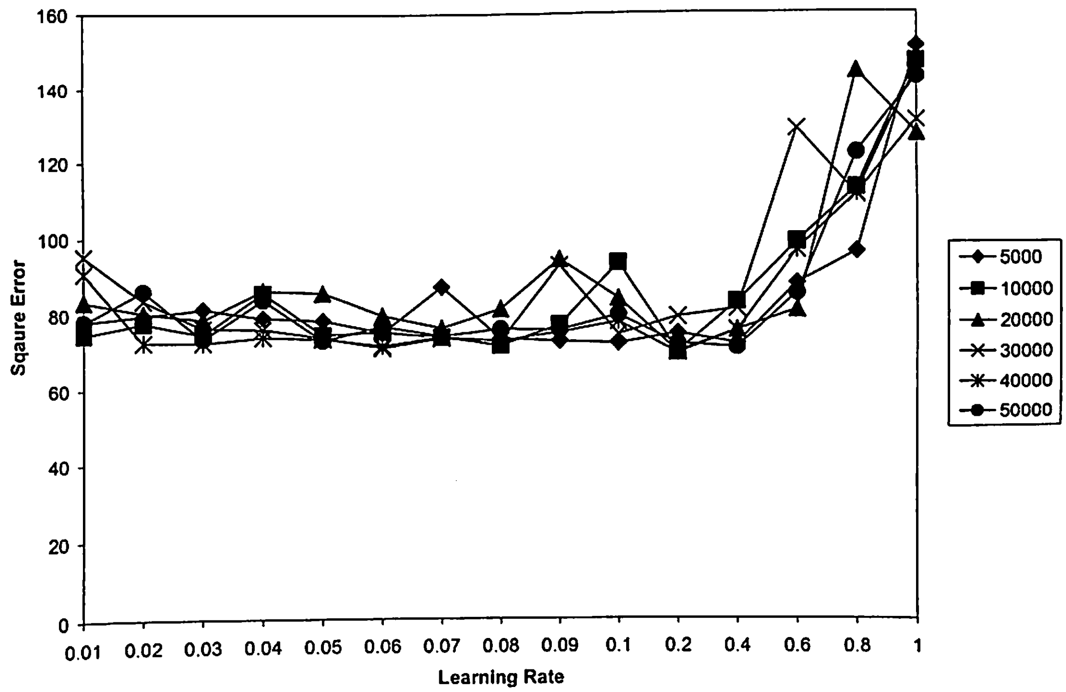


Fig. 6.111 Variation of square error value for various learning rates and epochs (Conscience rate = 0.001 and Group 7)

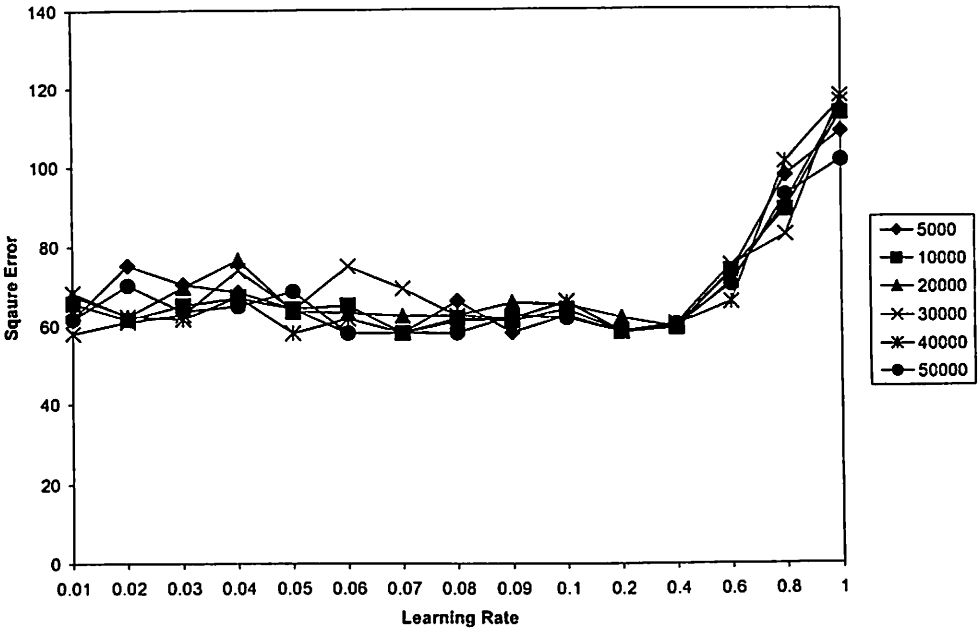


Fig. 6.112 Variation of square error value for various learning rates and epochs (Conscience rate = 0.001 and Group 8)

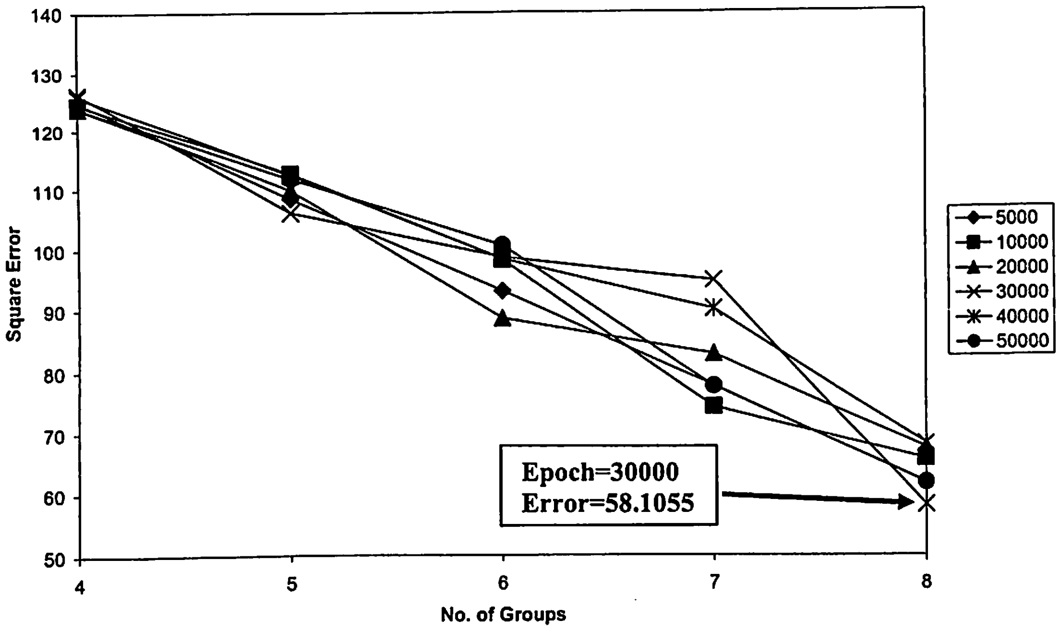


Fig. 6.113 (a) Variation of square error value for various groups and epochs (Learning rate = 0.01 and Conscience rate = 0.001)

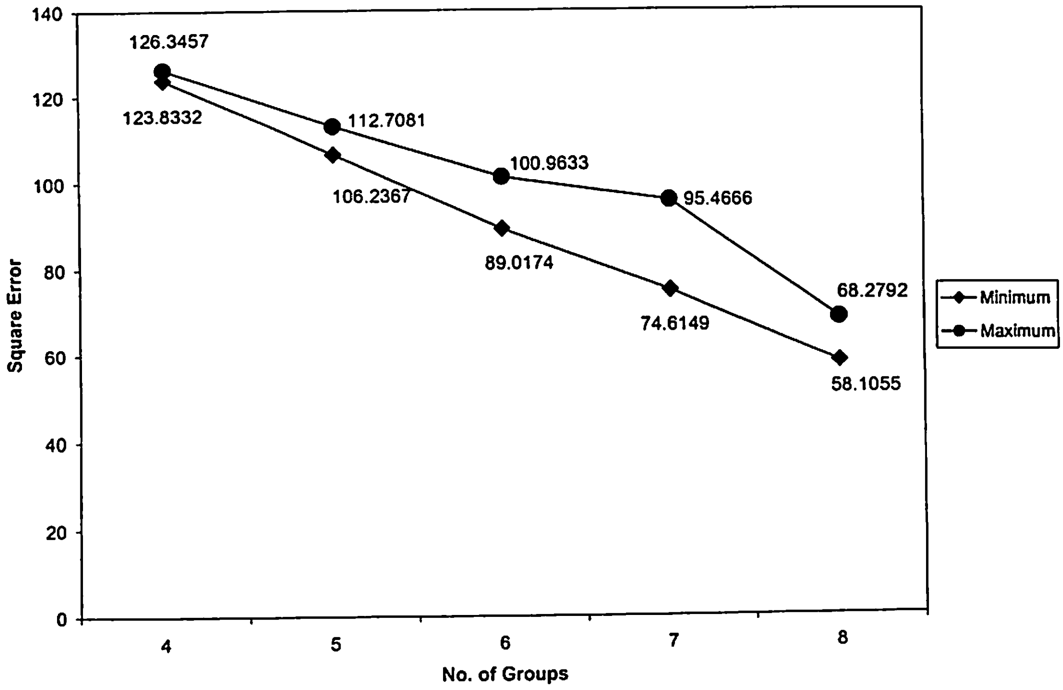


Fig. 6.113 (b) Variation of square error value for various groups

(Learning rate = 0.01 and Conscience rate = 0.001)

Table 6.36 Weights of the groups obtained by KANN methodology for the chosen parameters (Learning rate=0.01, Conscience rate=0.001, Groups=8, Epochs=30000)

Groups	LDW	TSI	CUW	PF	EI	CPR	EC
G1	1.7026	6.4736	4.4207	5.5640	18.1244	5.6878	3.8843
G2	1.7752	4.7563	5.4818	5.6223	17.2359	10.6046	4.7164
G3	1.0687	6.2101	3.6543	6.5588	20.4343	10.8935	6.3811
G4	1.7932	6.3411	5.6586	8.6681	20.6105	10.2175	4.3003
G5	1.7028	5.1967	6.3661	6.6764	22.7443	10.219	6.7048
G6	1.8477	5.3728	4.3027	3.5140	15.8146	8.8691	6.6123
G7	1.7210	7.2225	5.2465	7.6133	15.6362	12.6290	5.3639
G8	1.3224	5.5936	5.0101	7.0281	15.1037	9.4473	5.6876

Squared error value for specific irrigation subsystem falling in a specific group is obtained by summation of square of the difference between weight of each criterion obtained by KANN falling in that group (Table 6.36) and corresponding criterion values of irrigation subsystem falling in that group (Table 6.35 (b)). Criterion value of LDW for IS1 is 1.3043 and weight value of LDW for group 8 in which IS1 is falling is 1.3224. Square error values for criterion LDW is $(1.3043-1.3224)^2$. Similar computations are performed for all the criteria and summation of all such values gives the square error value i.e. $[(1.3043-1.3224)^2 + (6.6060-5.5936)^2 + (4.5977-5.0101)^2 + (7.7306-7.0281)^2 + (15.2813-15.1037)^2 + (8.6765-9.4473)^2 + (5.9187-5.6876)^2] = 2.3680$. Table 6.35 (b) presents the irrigation subsystems and corresponding groups after such procedure. It is observed from Table 6.35 (b) that groups G1, G2, G3, G4, G5, G6, G7, G8 consist of irrigation subsystems (IS7, IS16), (IS5, IS15), (IS3, IS10), (IS9, IS12), (IS4, IS8), (IS13, IS14), (IS6, IS11), (IS1, IS2) respectively.

Irrigation subsystem which has the minimum square error value in that group is chosen as group representative. Thus, instead of having sixteen irrigation subsystems, representative number from each group are used further for effective decision making. The irrigation subsystems IS16, IS15, IS3, IS9, IS4, IS13, IS11, IS1 having minimum total squared error values of 3.7439, 3.0613, 2.8198, 4.4751, 3.3983, 3.7196, 5.4452 and 2.3680 are found to be the representative strategies for the sixteen groups due to less values of square error. The groups are represented by G1, G2, G3, G4, G5, G6, G7 and G8 for further analysis. Resulting groups which are obtained from Kohonen classification methodology and representative irrigation subsystems of each group are presented in Table 6.35 (b).

The normalized payoff matrix after grouping is presented in Table 6.37 for further analysis such as for application of MCDM techniques.

Table 6.37 Normalized payoff matrix after Kohonen classification methodology

Groups	LDW	TSI	CUW	PF	EI	CPR	EC
G1	27	63	31	57	51	27	48
G2	34	59	46	49	47	59	37
G3	22	82	26	47	57	54	69
G4	45	65	47	78	54	46	46
G5	41	41	56	56	64	57	77
G6	49	56	27	33	48	42	71
G7	49	79	56	61	39	64	61
G8	36	75	39	66	43	45	64
MIN/WORST	22	41	26	33	39	27	37
MAX/BEST	49	82	56	78	64	64	77

6.5.3 Phase 3: Application of MCDM Techniques

Three MCDM techniques, namely, MCQA-2, MAUT and CP are employed to rank the irrigation subsystems after grouping (in this case there are eight groups). A detailed analysis is given in the following sections.

6.5.3.1 Multicriterion Q-Analysis-2 (MCQA-2)

An interactive computer program is developed in C environment to determine the ranking of the groups based on MCQA methodology. Inputs required such as the number of alternatives and criteria, weights of the criteria, payoff matrix or preference matrix, slicing threshold values and p value are stored in a file. Options are also provided to enter the data through keyboard. Output includes the input data that are provided, Project Satisfaction Index (PSI), Project Concordance Index (PCI), Project Discordance Index (PDI) for specified slicing level(s) and L_p - metric values for given p and corresponding ranking pattern as per the methodology explained in section 4.6.1. Fig. D-1 of Appendix D presents the flow chart of the computer program that is developed.

Preference matrix (U') (in this case it is the normalized payoff matrix as presented in Table 6.37) is used for further analysis. The number of slicing thresholds that are used in the present study are chosen as follows. There are 56 values in the preference matrix (8 groups and 7 criteria). For example, the number 49 appeared thrice in the preference matrix. But it was included as one slicing threshold instead of thrice. With this analysis 34 values are chosen as slicing thresholds which are combinedly used for the analysis and considered as optimal (Hiessl *et al*, 1985). These are 22, 26, 27, 31, 33, 34, 36, 37, 39, 41, 42, 43, 45, 46, 47, 48, 49, 51, 54, 56, 57, 59, 61, 63, 64, 65, 66, 69, 71, 75, 77, 78, 79 and 82. The PSI, PCI and PDI are calculated for each of the above slicing threshold values (Hiessl *et al*, 1985; Duckstein and Nobe, 1997; Raju and Nagesh Kumar, 2001) and presented in Table 6.38, Table 6.39 and Table 6.40. The procedure for calculating PSI, PCI and PDI is explained with an example (with reference to procedure as explained in Section 4.6.1) and presented in Appendix E.

PSI, PCI and PDI values for combined slicing threshold levels are determined by summation of individual PSI, PCI and PDI obtained for each slicing threshold level. These are presented in Table 6.41. Desired goals of these three indices PSIMAX, PCIMAX and PDIMAX are taken as the maximum values available among each index. These are 933.47, 799, 841 for PSI, PCI, PDI respectively. These values are kept uniform throughout the study. PSI, PCI and PDI values for combined slicing threshold levels are normalized with reference to PSIMAX, PCIMAX and PDIMAX and denoted as PSIN, PCIN and PDIN respectively and presented in Table 6.41. However, variations in PSIMAX, PCIMAX and PDIMAX are considered in sensitivity analysis studies.

Table 6.38 Project Satisfaction Index (PSI) for various slicing levels

PSI	22	26	27	31	33	34	36	37	39	41	42	43	45	46	47	48	49
G1	22.00	26.00	27.00	23.90	21.55	22.20	23.51	24.16	25.47	26.78	27.43	28.08	29.39	30.04	30.69	31.35	27.47
G2	22.00	26.00	27.00	31.00	33.00	34.00	34.70	35.66	33.98	35.72	36.59	37.47	39.21	40.08	35.41	19.11	19.50
G3	22.00	25.06	22.84	26.22	27.91	28.76	30.45	31.30	32.99	34.68	35.53	36.37	38.07	38.91	39.76	34.98	35.71
G4	22.00	26.00	27.00	31.00	33.00	34.00	36.00	37.00	39.00	41.00	42.00	43.00	45.00	44.33	31.89	26.91	27.47
G5	22.00	26.00	27.00	31.00	33.00	34.00	36.00	37.00	39.00	41.00	36.78	37.66	39.41	40.28	41.16	42.03	42.91
G6	22.00	26.00	27.00	27.35	29.11	26.01	27.54	28.30	29.83	31.36	32.13	24.60	25.75	26.32	26.89	27.46	10.62
G7	22.00	26.00	27.00	31.00	33.00	34.00	36.00	37.00	39.00	26.43	27.07	27.72	29.01	29.65	30.30	30.94	31.59
G8	22.00	26.00	27.00	31.00	33.00	34.00	36.00	35.66	37.59	34.68	35.53	36.37	22.07	13.69	13.99	14.29	14.59

PSI	51	54	56	57	59	61	63	64	65	66	69	71	75	77	78	79	82
G1	28.59	11.08	11.49	11.70	5.20	5.37	5.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G2	14.33	15.17	15.73	16.01	16.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G3	37.17	39.35	30.01	30.55	10.65	11.01	11.38	11.56	11.74	11.92	12.46	6.25	6.61	6.78	6.87	6.96	7.22
G4	28.59	30.27	11.49	11.70	12.11	12.52	12.93	13.13	13.34	7.73	8.08	8.32	8.79	9.02	9.14	0.00	0.00
G5	44.66	47.29	49.04	36.52	26.42	27.32	28.22	28.66	6.01	6.10	6.38	6.57	6.94	7.12	0.00	0.00	0.00
G6	9.21	9.75	10.11	5.27	5.46	5.64	5.83	5.92	6.01	6.10	6.38	6.57	0.00	0.00	0.00	0.00	0.00
G7	31.03	32.85	34.07	27.96	28.94	29.92	17.70	17.98	5.73	5.81	6.08	6.25	6.61	6.78	6.87	6.96	0.00
G8	15.18	16.08	16.67	16.97	17.56	18.16	18.75	19.05	13.34	13.54	6.08	6.25	6.61	0.00	0.00	0.00	0.00

Table 6.39 Project Concordance Index (PCI) for various slicing levels

PCI	22	26	27	31	33	34	36	37	39	41	42	43	45	46	47	48	49
G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0
G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	48	49
G4	0	0	0	0	0	0	0	0	0	0	42	43	45	46	47	0	0
G5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	48	49
G6	0	0	0	0	0	0	0	0	0	0	0	0	0	46	47	48	0
G7	0	0	0	0	0	0	0	0	0	0	0	0	0	46	94	96	98
G8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PCI	51	54	56	57	59	61	63	64	65	66	69	71	75	77	78	79	82
G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G3	51	54	56	57	0	0	0	0	65	66	69	0	0	0	0	0	0
G4	0	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G5	51	54	56	57	59	61	63	64	0	0	0	0	0	0	0	0	0
G6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G7	51	54	56	57	59	61	63	64	0	0	0	0	0	0	0	0	0
G8	0	0	0	0	0	0	63	64	0	66	0	0	0	0	0	0	0

Table 6.40 Project Discordance Index (PDI) for various slicing levels

PDI	22	26	27	31	33	34	36	37	39	41	42	43	45	46	47	48	49
G1	0	0	0	31	33	34	36	37	39	41	42	43	45	0	0	0	0
G2	0	0	0	0	0	0	0	0	39	41	42	43	45	46	47	48	49
G3	0	0	27	31	0	0	0	0	0	0	0	0	0	0	0	48	49
G4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	48	0
G5	0	0	0	0	0	0	0	0	0	0	42	43	45	46	47	48	49
G6	0	0	0	0	0	34	36	37	39	41	42	43	45	46	47	48	49
G7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G8	0	0	0	0	0	0	0	0	0	0	0	0	45	46	47	48	49

PDI	51	54	56	57	59	61	63	64	65	66	69	71	75	77	78	79	82
G1	0	54	0	0	59	0	0	0	0	0	0	0	0	0	0	0	0
G2	51	54	56	57	0	61	63	0	0	0	0	0	0	0	0	0	0
G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G5	51	54	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G6	51	54	56	114	59	0	0	0	0	0	0	0	0	0	0	0	0
G7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.41 Total project indices and their normalized values

Groups	Total PSI	Total PCI	Total PDI	PSIN	PCIN	PDIN
G1	526.01	48	494	0.56	0.06	0.59
G2	618.23	0	742	0.66	0.00	0.88
G3	800.02	562	155	0.86	0.70	0.18
G4	783.74	277	95	0.84	0.35	0.11
G5	933.47	609	481	1.00	0.76	0.57
G6	530.53	141	841	0.57	0.18	1.00
G7	789.24	799	0	0.85	1.00	0.00
G8	651.71	193	235	0.69	0.24	0.28

The L_p - metric values (with respect to p) are computed by the program as per Eq. 4.33. The group having minimum L_p - metric value is taken as the best and accordingly ranking pattern is made for other groups. Table 6.42 presents L_p - metric values and ranks obtained for three different values of p=1, 2 and ∞(Tecle *et al*, 1988).

Table 6.42 L_p - metric values and final ranks by MCQA-2

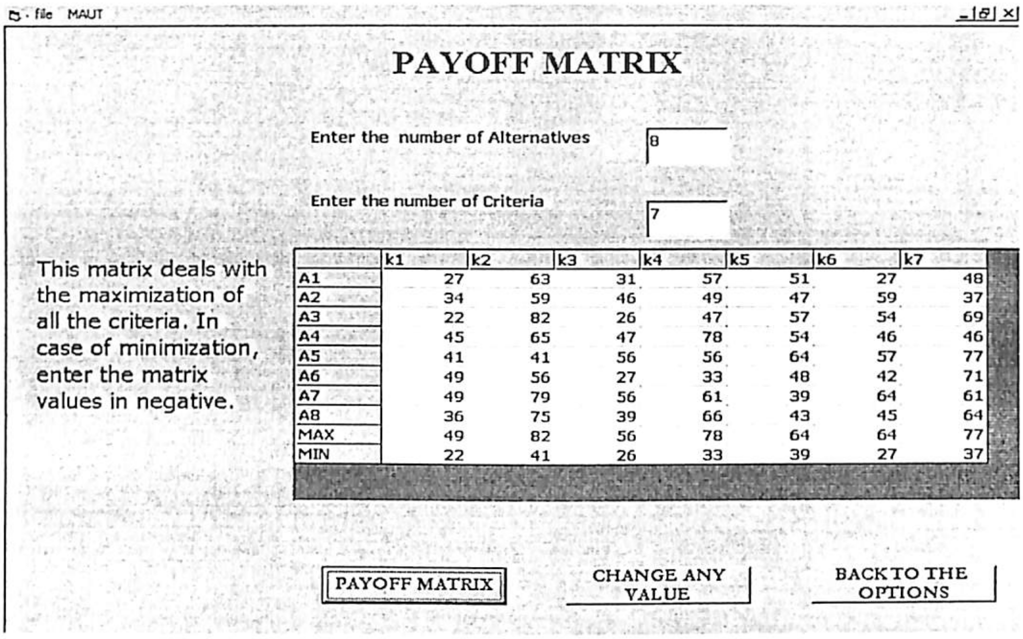
Groups	p=1		p=2		p=∞	
	L_p - metric value	Final ranks	L_p - metric value	Final ranks	L_p - metric value	Final ranks
G1	1.964	6	1.191	6	0.941	6
G2	2.220	7	1.376	8	1.025	8
G3	0.624	2	0.377	2	0.297	2
G4	0.927	4	0.682	4	0.653	4
G5	0.810	3	0.619	3	0.572	3
G6	2.255	8	1.365	7	1.014	7
G7	0.155	1	0.155	1	0.155	1
G8	1.340	5	0.863	5	0.758	5

It is observed that ranking pattern for p=2 and $p=\infty$ are the same for each group whereas there is an interchange of positions 7 and 8 for G2 and G6 in case of p=1. Group G7 is found to be the best having low L_p - metric value of 0.155 for $p = 1,2,\infty$ followed by group G3 with L_p - metric values of 0.624, 0.377, 0.297 respectively for p=1, 2, ∞. Groups G2 and G6 are found to be least preferred.

6.5.3.2 Multi Attribute Utility Theory (MAUT)

An interactive computer program is developed in visual basic environment to determine the ranking of alternatives based on MAUT methodology. Visual Basic is an ideal programming language for developing sophisticated professional applications which makes use of Graphical User Interface for creating robust and powerful applications (Perry, 1998). The Graphical User Interface uses illustrations for text which enable users to interact with the application. Inputs such as number of alternatives and criteria, payoff matrix, subjective ranking of the scaling constants for attributes (criteria), indifference values between the scaling constants and probability p' value are to be provided in a sequential manner (Section 4.6.2). Payoff matrix can be either given through an input file or can be entered directly through keyboard. A provision for changing the input values is also incorporated in the program. Output includes the utility values for each element in the payoff matrix, scaling constants, overall scaling constant and final utility values based on which ranking is done. The program has the capability of displaying the ranking pattern in the form of a bar chart. Fig. 6.114 presents the sample screen of MAUT program in which the number of alternatives, criteria and payoff matrix are visible. Fig. D-2 of Appendix D presents the flow chart of the computer program that is developed.

Duckstein *et al* (1994) assumed that the axiomatic basis underlying MAUT is approximately satisfied and that there exists a utility function to represent the decision maker's preference. It is assumed that the conditions of preferential and utility independence are satisfied and multiplicative form of equation is valid for combining single attribute utility functions into a multi attribute utility function (Raju and Pillai, 1999). The seven performance criteria LDW, TSI, CUW, PF, EI, CPR and EC used in this study are denoted as C_1 to C_7 for representing in equations. The various steps to find out the multi attribute utility function are as follows:



	k1	k2	k3	k4	k5	k6	k7
A1	27	63	31	57	51	27	48
A2	34	59	46	49	47	59	37
A3	22	82	26	47	57	54	69
A4	45	65	47	78	54	46	46
A5	41	41	56	56	64	57	77
A6	49	56	27	33	48	42	71
A7	49	79	56	61	39	64	61
A8	36	75	39	66	43	45	64
MAX	49	82	56	78	64	64	77
MIN	22	41	26	33	39	27	37

Fig. 6.114 Sample screen for entering payoff matrix in MAUT methodology

(a) Ranking of scaling constant (k_j) for the criteria

The scaling constants of the criteria are to be ranked based on their priority. The question is posed as "given that all the seven criteria are at their worst levels, which criterion is preferred to be slightly at a better level, leaving all the other six at their worst levels?". Suppose the response is "economic impact" then, value of k_5 is greater than k_1 to k_4 and k_6, k_7 where k_1 to k_7 are scaling constants corresponding to seven criteria C_1 to C_7. The procedure is repeated to rank the remaining criteria. The ranking of criteria based on the response from decision maker is $k_5 > k_6 > k_3 > k_4 > k_7 > k_2 > k_1$. It is observed that similar ranking is obtained when AHP is employed for determining the weights and this also confirms the consistency of the decision maker, while evaluating the priority of the criteria. Fig. 6.115 shows the sample screen for entering the ranking of criteria.

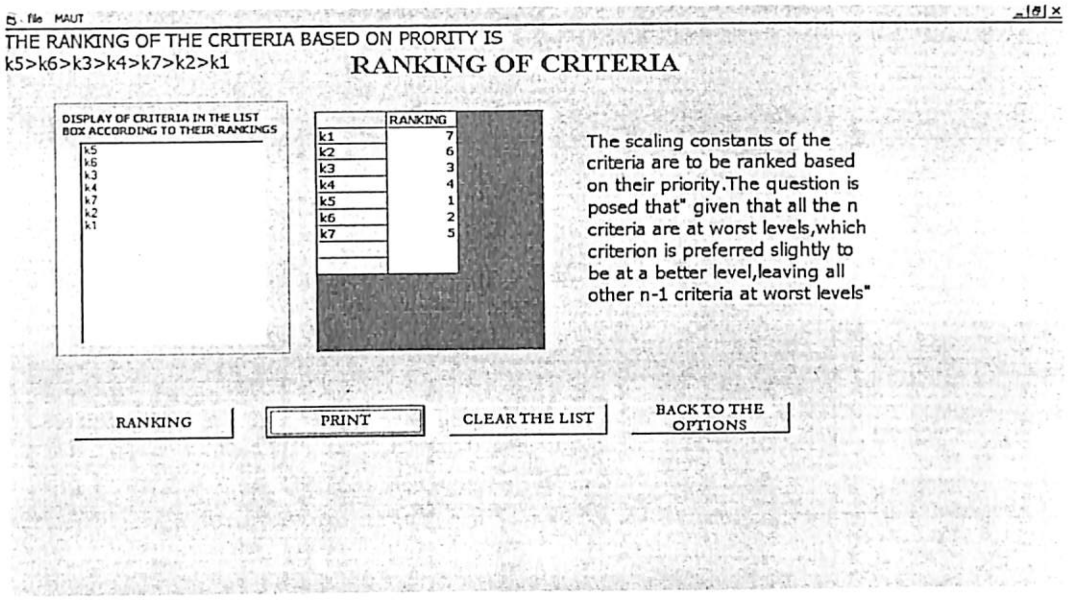


Fig. 6.115 Sample screen for entering the ranks of criteria in MAUT methodology

(b) Determination of indifference points

To establish the actual magnitude of the scaling constants, concept of indifference curve (contours of equal utility) is used. For example, it can be observed from Fig. 6.116 (a) that for criteria C_5 and C_6 (the two highest ranked criteria), the decision maker is indifferent between (C_6=best, C_5=worst) and (C_6=worst, C_5=y) where y is some value less than the best value of C_5 while all other criteria are at any fixed level. The pair of indifference points (equal utility) for the above case are (64, 39), (27, y), where y=60. Similar procedure is adopted for all other pairs. The decision maker was requested to assume linearity to represent the characteristics that fall in between these values because they may not be represented in the scale. The pair of indifference values obtained from the decision maker is presented in Table 6.43 and the sample screen for the same is shown in Fig. 6.117.

Table 6.43 Pair of indifference points in MAUT methodology

Criteria	(C_5, C_6)	(C_5, C_3)	(C_5, C_4)	(C_5, C_7)	(C_5, C_2)	(C_5, C_1)
Value y	60	56	55	51	50	42

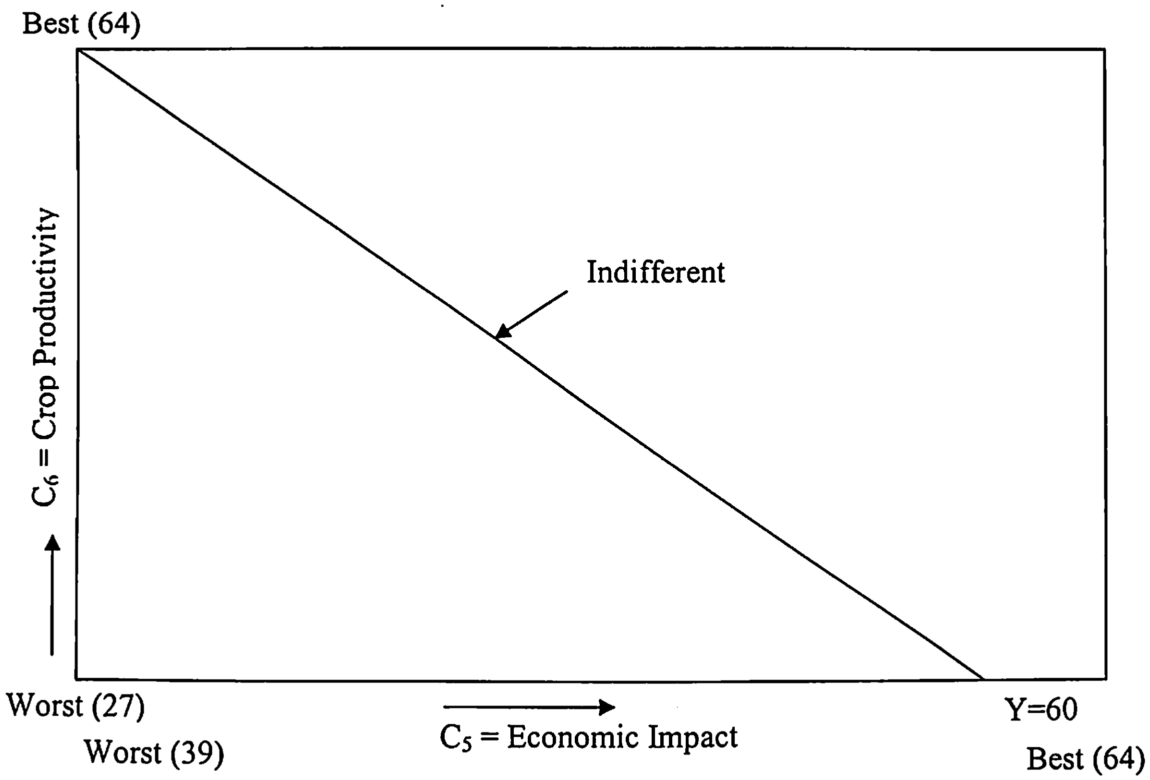


Fig. 6.116 (a) Tradeoffs made in the assessment of scaling constants

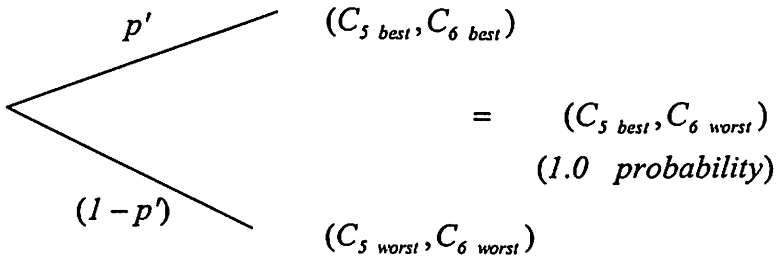


Fig. 6.116 (b) Procedure to assess the value probability p'

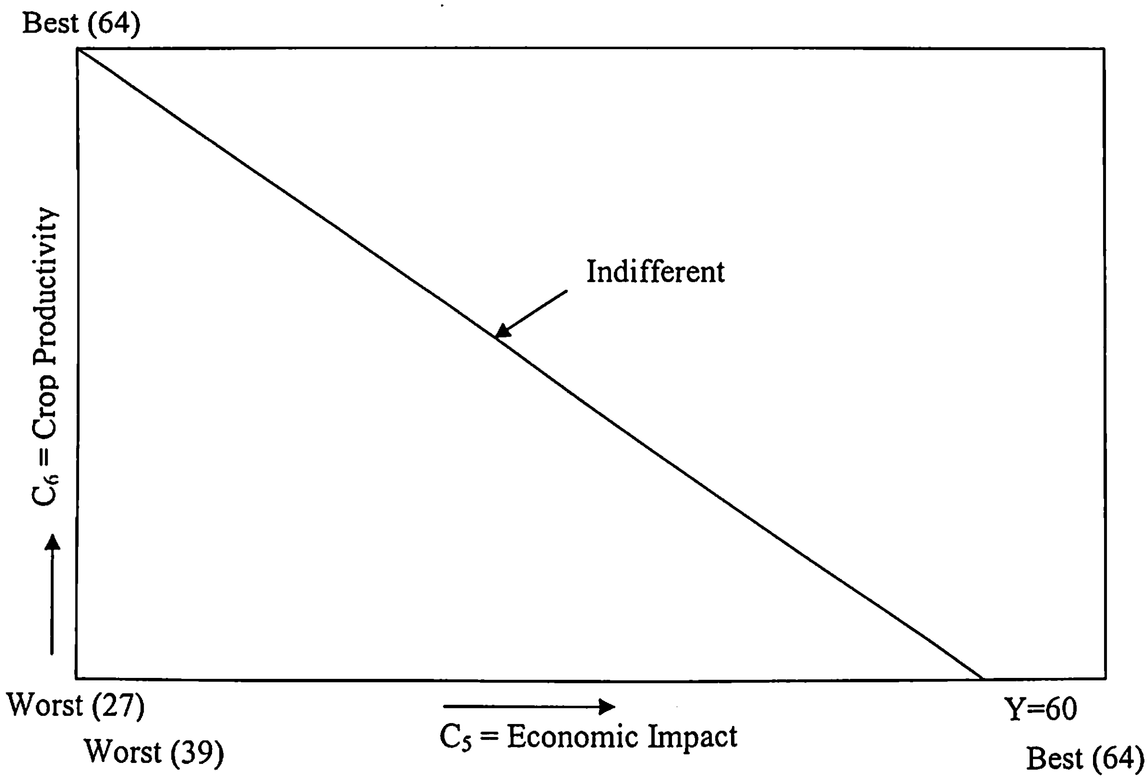


Fig. 6.116 (a) Tradeoffs made in the assessment of scaling constants

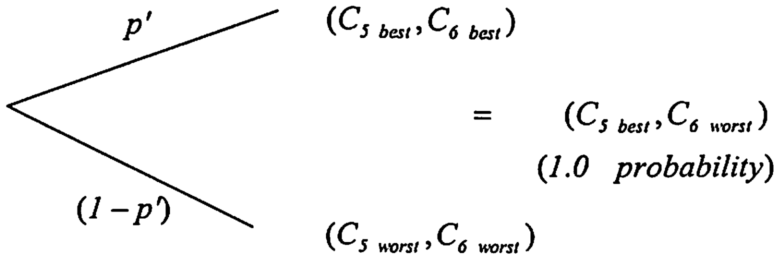


Fig. 6.116 (b) Procedure to assess the value probability p'

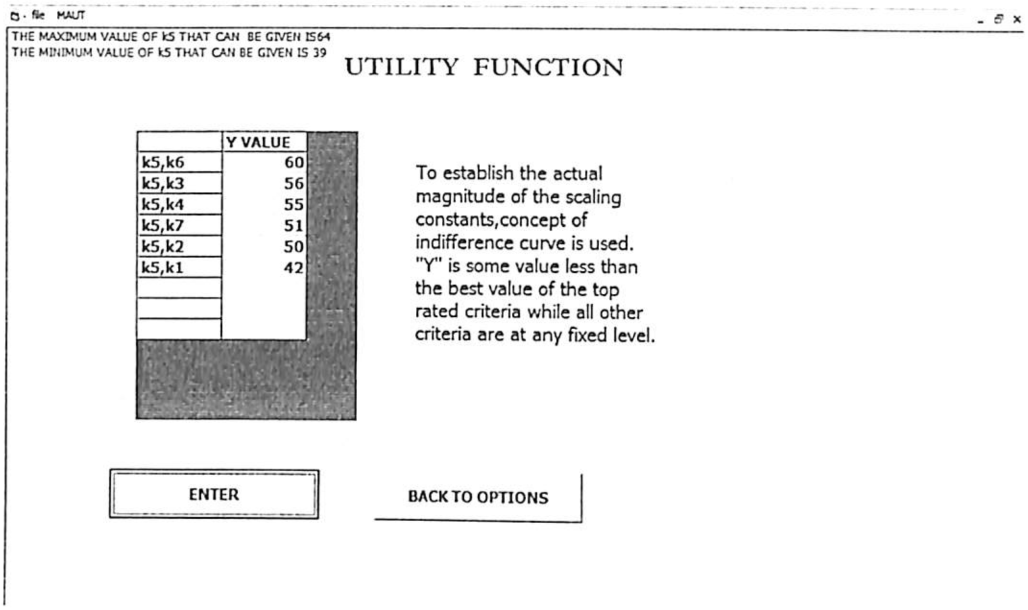


Fig. 6.117 Sample screen for entering the utility value

(c) Derivation of multi attribute utility function

The multiplicative form of equation for the seven criteria case becomes (with reference to Eq. 4.35)

$$1 + ku(C_1, C_2, ..., C_7) = \prod_{j=1}^{7}\left[1 + kk_j u_j(C_j)\right] \quad (6.1)$$

Equating the utility values of two indifference points (C_5, C_6) in Table 6.43, the multiplicative form of Eq. 6.1 (for pair of highly ranked criteria C_5 and C_6) transforms into

$$\underset{(worst)}{\left[1 + kk_5.u_5(C_5)\right]}\ \underset{(best)}{\left[1 + kk_6.u_6(C_6)\right]} = \underset{(y)}{\left[1 + kk_5.u_5(C_5^{'})\right]}\ \underset{(worst)}{\left[1 + kk_6.u_6(C_6^{'})\right]} \quad (6.2)$$

where $C_5^{'}$ and $C_6^{'}$ are indifference points for criteria C_5 and C_6 respectively.

(C_6=best, C_5=worst)	(C_6=worst, C_5=y)
(64, 39)	(27, 60)
$u_6(best) = 1 \quad u_5(worst) = 0$	$u_6(worst) = 0 \quad u_5(y) = ?$

Assuming linear utility function for intermediate values between best and worst combinations, for criteria C_5, $u_5(best) = u_5(64) = 1$, $u_5(worst) = u_5(39) = 0$, and for 60 it is linearly interpolated as 0.84 i.e., $u_5(60) = 0.84$.

For pairs C_5 and C_6 the Eq. 6.2 reduces to

$$(1 + kk_5 \times 0)(1 + kk_6 \times 1) = [1 + kk_5 \times u_5(60)][1 + kk_6 \times 0] \tag{6.3}$$

$$1 + kk_6 = 1 + kk_5 u_5(60) \tag{6.4}$$

$$k_6 = k_5 u_5(60) \tag{6.5}$$

$$k_6 = 0.84 k_5 \tag{6.6}$$

A similar procedure is adopted for other pairs and the following relationship is obtained.

For pairs C_5 and C_3; $k_3 = 0.68k_5$ (6.7)

For pairs C_5 and C_4; $k_4 = 0.64k_5$ (6.8)

For pairs C_5 and C_7; $k_7 = 0.48k_5$ (6.9)

For pairs C_5 and C_2; $k_2 = 0.44k_5$ (6.10)

For pairs C_5 and C_1; $k_1 = 0.12k_5$ (6.11)

Even though any number of pairs can be chosen for indifference points of equal utility like (C_5, C_1), (C_5, C_2), (C_5, C_3), (C_5, C_4), (C_5, C_6), (C_5, C_7), (C_6, C_1), (C_6, C_2), (C_6, C_3), (C_6, C_4), (C_6, C_5), (C_6, C_7) etc., only six constants can be made out of any number of pairs as evident from Eqs. 6.6 to 6.11.

In the above equations, the total number of unknowns is eight including seven scaling constants (k_1 to k_7) and one overall scaling constant k. A total of six equations are formulated based on indifference tradeoff relationship between the two criteria (as observed from Eqs. 6.6 to 6.11).

One more equation is introduced to assess the overall scaling constant k, by estimating the probability p' for which the decision maker is indifferent between lottery A^* over the best and worst combinations of two highly ranked criteria i.e., $(C_{5\ best}, C_{6\ best})$, $(C_{5\ worst}, C_{6\ worst})$ versus lottery B^*, i.e., $(C_{5\ best}, C_{6\ worst})$ for certain as shown in Fig. 6.116 (b). The multiplicative form of equation for two criteria case obtained from Eq. 6.1 becomes

$$1 + ku(C_5, C_6) = (1 + kk_5u_5(C_5))(1 + kk_6u_6(C_6)) \qquad (6.12)$$

$$u(C_5, C_6) = \left[\frac{(1 + kk_5u_5(C_5))(1 + kk_6u_6(C_6)) - 1}{k}\right] \qquad (6.13)$$

Equating the utility values of lottery A^* and B^* (for two highly ranked criteria) using Eq. 6.13 becomes

$$p'.u(C_{5\ best}, C_{6\ best}) + (1 - p').u(C_{5\ worst}, C_{6\ worst}) = u(C_{5\ best}, C_{6\ worst}) \quad (6.14)$$

where,

$$u(C_{5\ best}, C_{6\ best}) = \left[\frac{(1 + kk_5 \times 1)(1 + kk_6 \times 1) - 1}{k}\right] = k_5 + k_6 + kk_5k_6$$

$$u(C_{5\ worst}, C_{6\ worst}) = \left[\frac{(1 + kk_5 \times 0)(1 + kk_6 \times 0) - 1}{k}\right] = 0$$

$$u(C_{5\ best}, C_{6\ worst}) = \left[\frac{(1 + kk_5 \times 1)(1 + kk_6 \times 0) - 1}{k}\right] = k_5$$

Substituting the values, Eq. 6.14 becomes

$$p' \times (k_5 + k_6 + kk_5k_6) + (1 - p') \times 0 = k_5 \qquad (6.15)$$

and results in

$$k_5 = p'(k_5 + k_6 + kk_5k_6) \qquad (6.16)$$

A probability value (p') of 0.65 is given by the decision maker. Then the above equation is reduced to

$$k_5 = 0.65(k_5 + 0.84k_5 + 0.84kk_5^2) \qquad (6.17)$$

$$k_5 = 0.65(1.84k_5 + 0.84kk_5^2) \qquad (6.18)$$

Then, both sides of Eq. 6.18 is divided by k_5 and this equation is further simplified as

$$k_5 = \frac{-0.36}{k} \tag{6.19}$$

If all the criteria are set at their best levels, Eq. 6.1 then becomes

$$1 + k = (1 + kk_1)(1 + kk_2)(1 + kk_3)(1 + kk_4)(1 + kk_5)(1 + kk_6)(1 + kk_7) \tag{6.20}$$

substituting the relationships as observed from Eqs. 6.6 to 6.11 and Eq. 6.19 in Eq. 6.20 yields the value of k=-0.7288.

Table 6.44 presents the scaling constants and the values of overall scaling constant (k) obtained as per the methodology explained in Section 4.6.2 and inputs from the decision maker. Table 6.45 presents the utility values and corresponding ranks of the eight groups. The irrigation subsystem which provides the highest degree of utility with respect to all the criteria is taken as the best irrigation subsystem. It is observed that group G5 is found to be the best with a utility value of 1 followed by group G7 with a utility value of 0.9191. It is observed that the negative value of k represents the risk aversive nature of the decision maker (Goicoechea *et al*, 1982). However, a study is also made to assess the impact of variation of scaling constants and p' values on ranking pattern which is presented in the sensitivity analysis section.

Table 6.44 Scaling constants for $p' = 0.65$ as obtained by MAUT methodology

k_1	k_2	k_3	k_4	k_5	k_6	k_7	k
0.0591	0.2167	0.3350	0.3153	0.4926	0.4138	0.2364	-0.7288

Table 6.45 Utility values and final ranks in MAUT methodology

Groups	G1	G2	G3	G4	G5	G6	G7	G8
Utility	0.5477	0.7431	0.8387	0.8839	1.0000	0.5734	0.9191	0.7560
Rank	8	6	4	3	1	7	2	5

6.5.3.3 Compromise Programming (CP)

An interactive computer program is developed for CP in Visual Basic environment which makes use of Graphical User Interface. Fig. 6.118 presents the sample screen of CP in which the number of alternatives, criteria, payoff matrix and parameter p are given as inputs by the user. The user has the flexibility to give any number of alternatives and criteria and change the values in the payoff matrix and weights. The value of parameter p can also be modified to know the sensitivity of the ranking pattern. Maximum, minimum and ideal value for each criterion is computed by the program itself based on the given values in the payoff matrix. The L_p - metric values (with respect to p) and ranking pattern are computed by the program as per CP methodology (Section 4.6.3). The procedure for calculating L_p - metric value is explained with an example and presented in Appendix E. The group having minimum L_p - metric value is taken as the best compromise solution and accordingly ranking pattern is made for other groups. Three compromise sets are calculated for p=1, 2 and ∞(Tecle *et al*, 1988). Fig. D-3 of Appendix D presents the flow chart of the computer program that is developed.

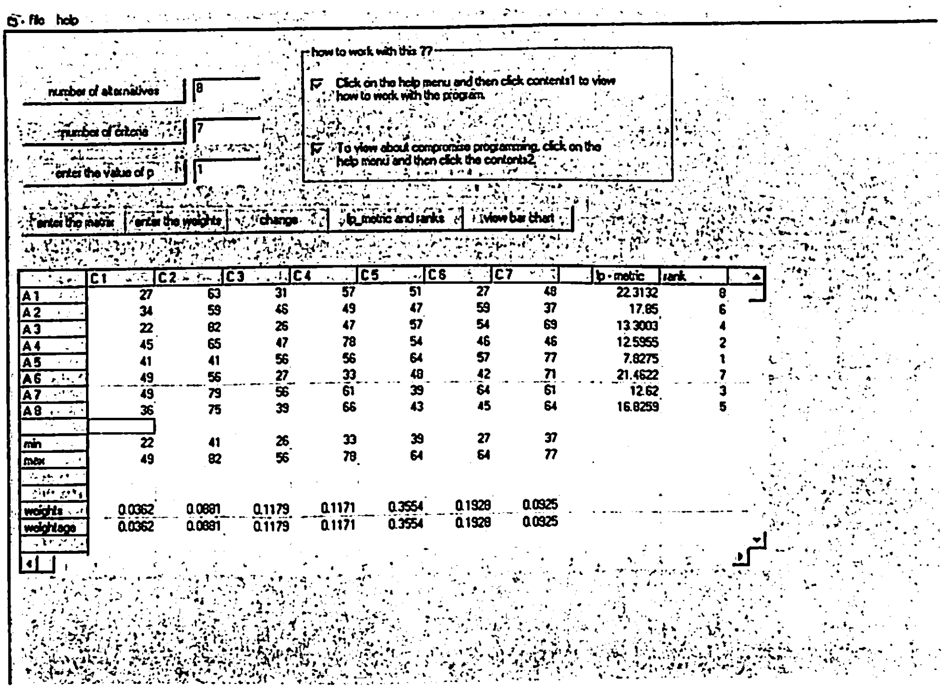


Fig. 6.118 Sample screen of Compromise Programming methodology

Table 6.46 presents the L_p - metric values for p=1, 2 and ∞ and corresponding ranking pattern. It is observed that group G5 occupies the first position due to its low L_p - metric value of 7.8275 for p=1, 4.6464 for p=2 and 3.6242 for $p=\infty$ whereas the second position is occupied by G4 for p=1 and G3 for p=2, ∞. Provision of graphical representation of ranking pattern in the form of a bar chart is also made in the program and presented in Fig. 6.119 for p=1.

Table 6.46 L_p - metric values and final ranks by CP methodology

Groups	p=1		p=2		$P=\infty$	
	L_p - metric value	Final ranks	L_p - metric value	Final ranks	L_p - metric value	Final ranks
G1	22.3132	8	9.8793	8	7.1429	6
G2	17.8500	6	8.2731	4	6.0482	5
G3	13.3003	4	6.0908	3	3.8489	3
G4	12.5955	2	6.0239	2	3.7906	2
G5	7.8275	1	4.6464	1	3.6242	1
G6	21.4622	7	9.7641	7	5.9321	5
G7	12.6200	3	9.2286	6	8.8850	8
G8	16.8259	5	8.7841	5	7.4640	7

6.5.4 Final Rankings

The rankings obtained by all the three MCDM techniques, namely, MCQA-2, MAUT and CP are presented in Table 6.47. It is observed that G7 is ranked first by MCQA-2 technique whereas G5 is ranked first by MAUT and CP techniques. It is observed that G5 and G7 are found to have potential for further investigations. Fig. 6.120 presents the ranking pattern of different groups obtained by different MCDM techniques. Different ranking patterns obtained by various techniques may be due to the various parameters involved in the different MCDM techniques. These are PCIMAX, PSIMAX, PDIMAX, weights of the criteria and p values in MCQA-2, probability p' and scaling constant values in MAUT and parameter p in CP. However, these techniques are tested for extensive sensitivity analysis for robustness in ranking.

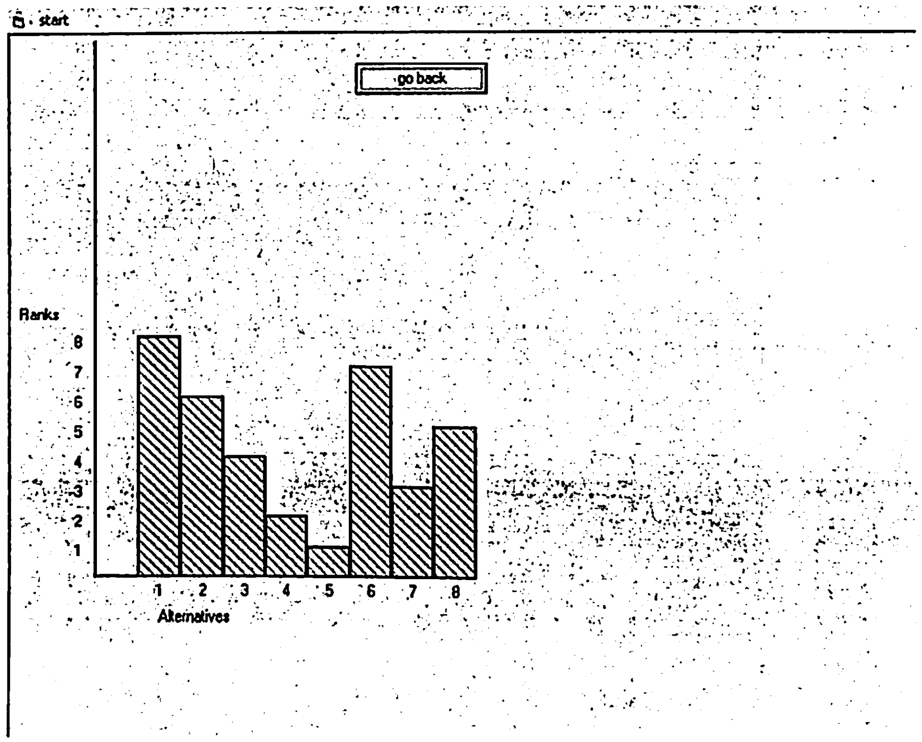


Fig. 6.119 Sample screen of a bar chart for representing ranks of alternatives for p=1

Table 6.47 Final ranks obtained by different MCDM techniques

Groups	MCQA-2			MAUT	CP		
	p=1	p=2	p=∞		p=1	p=2	p=∞
G1	6	6	6	8	8	8	6
G2	7	8	8	6	6	4	5
G3	2	2	2	4	4	3	3
G4	4	4	4	3	2	2	2
G5	3	3	3	1	1	1	1
G6	8	7	7	7	7	7	5
G7	1	1	1	2	3	6	8
G8	5	5	5	5	5	5	7

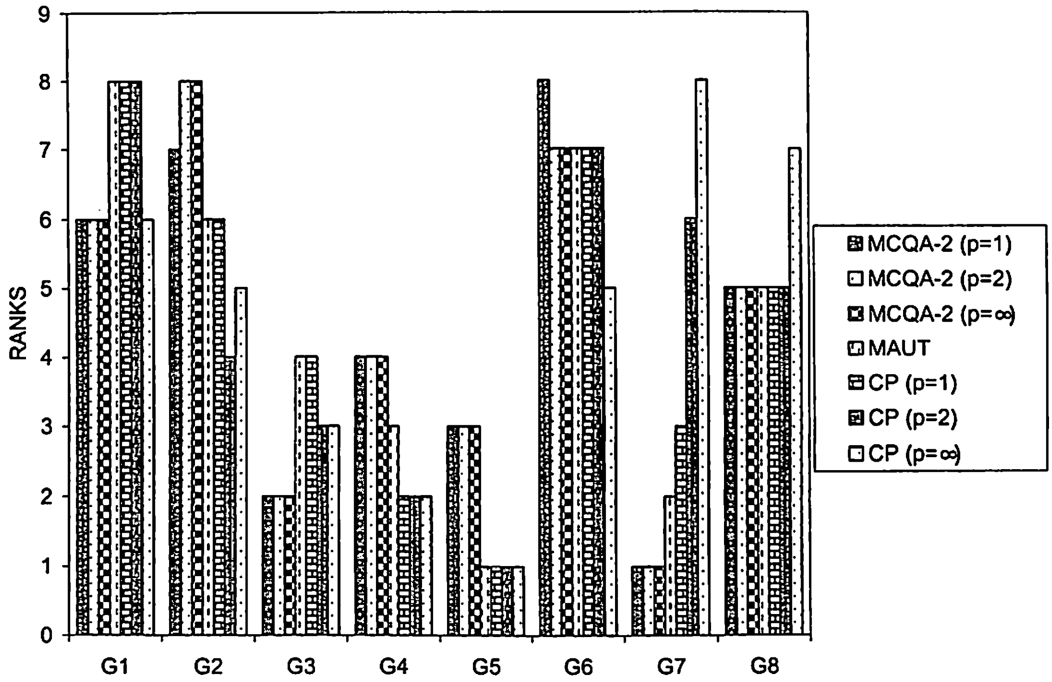


Fig. 6.120 Comparison of ranks obtained from different MCDM techniques

6.5.5 Correlation Coefficients

Spearman Rank Correlation (SRC) technique is used to compute correlation coefficient (R) between different MCDM techniques. Three MCDM techniques are employed resulting in six scenarios i.e., MCQA-2 (p=1), MCQA-2 (p=2, ∞), MAUT, CP (p=1), CP (p=2) and CP (p=∞). Each scenario is correlated to the other five scenarios resulting in 30 combinations. Since the correlation between any two scenarios say A'' and B'' is same as that of B'' and A'', out of 30 only 15 combinations are needed to be evaluated. Table 6.48 presents the SRC coefficient value R between different scenarios.

Low correlation coefficient value of 0.1071 is observed between MCQA-2 (p=2, ∞) and CP (p=∞). A similar trend is observed between MCQA-2 (p=1) and CP (p=∞) with an R value of 0.1071. R value of 0.3571 is observed between MCQA-2 (p=2, ∞) and CP (p=2) whereas it is 0.4286 between MCQA-2 (p=1) and CP (p=2). High values of correlation are observed between MCQA-2 (p=1) and MCQA-2 (p=2, ∞) with a value of 0.9762. The correlation value between MCQA-2 (p=1) and MAUT is 0.8095 while it is 0.7857 between MCQA-2 (p=2, ∞) and MAUT. R value of 0.9762 is observed between MAUT and CP (p=1). It is 0.7976 in case of CP (p=2) and CP ($p=\infty$). Correlation value of 0.7143 is observed between MCQA-2 (p=2, ∞) and CP (p=1) and 0.7381 between MAUT and CP (p=2). Low correlation coefficient of 0.3929 is observed between MAUT and CP ($p=\infty$) whereas it is 0.5357 between CP (p=1) and CP ($p=\infty$). The range of correlation coefficients is from 0.1071 to 0.9762 (excluding the diagonals which have a value of 1).

Table 6.48 Spearman rank correlation coefficient (R) values between different MCDM techniques

	MCQA-2 (p=1)	MCQA-2 (p=2, ∞)	MAUT	CP (p=1)	CP (p=2)	CP ($p=\infty$)
MCQA-2 (p=1)	1.0000	0.9762	0.8095	0.7381	0.4286	0.1071
MCQA-2 (p=2, ∞)		1.0000	0.7857	0.7143	0.3571	0.1071
MAUT			1.0000	0.9762	0.7381	0.3929
CP (p=1)				1.0000	0.8333	0.5357
CP (p=2)					1.0000	0.7976
CP ($p=\infty$)						1.0000

6.5.6 Sensitivity Analysis

A number of parameters are required in each technique to determine the final ranking. A careful selection of these parameters is important because the final ranking is based on the values of these parameters. So the effect of small changes in the chosen values of parameters on ranking pattern is investigated by carrying out sensitivity analysis studies. A brief discussion is as follows:

6.5.6.1 Multicriterion Q-Analysis-2 (MCQA-2)

Effects of slicing threshold values are studied on the ranking pattern. These are based on the minimum and maximum values in the preference matrix i.e., 22 and 82 respectively (Table 6.37). Twelve slicing levels 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 and 80 are combinedly studied for the analysis. It is observed that the ranking pattern for p=1, 2 is 6, 8, 2, 4, 3, 7, 1, 5 (ranking pattern in order of the groups) and for $p=\infty$, it is 6, 8, 1, 4, 3, 7, 2, 5 (ranking pattern in order of the groups). It is observed that either G7 or G3 occupies the first and the second positions respectively. The position of other irrigation subsystems remains same. R value for p=1, 2 and $p=\infty$ is 0.9762. Numerous runs are made in this direction and observed that slicing thresholds have significant effect on the ranking pattern.

Similarly, the effect of PSIMAX, PCIMAX, PDIMAX is also studied on the ranking pattern. In this regard, PSIMAX, PCIMAX, PDIMAX values obtained from the analysis (i.e. 933.47, 799 and 841) are increased by 1, 2, 5, 10, 15 and 20 %. Table 6.49 presents the PSIMAX, PCIMAX, PDIMAX values for this percentage increase. A total of 18 combinations are evaluated (6 scenarios of indices for p=1, 2, ∞) and three groups of ranking is observed (denoted as T1, T2, T3) and is presented in Table 6.50. It is observed that groups G7, G3 remain in the first and second positions. Table 6.51 shows R values for the same. It is observed that a good correlation ranging from 0.9286 to 0.9762 exists (excluding diagonals which are having a value of 1).

Table 6.49 PSIMAX, PCIMAX, PDIMAX values for sensitivity analysis studies in MCQA-2 methodology

% increase	PSIMAX	PCIMAX	PDIMAX
1	942.80	806.99	849.41
2	952.14	814.98	857.82
5	980.14	838.95	883.05
10	1026.82	878.90	925.10
15	1073.49	918.85	967.15
20	1120.16	958.80	1009.20

Table 6.50 Sensitivity on final ranks due to change in PSIMAX, PCIMAX, PDIMAX values in MCQA-2 methodology

	T1	T2	T3
G1	6	6	7
G2	7	8	8
G3	2	2	2
G4	4	4	4
G5	3	3	3
G6	8	7	6
G7	1	1	1
G8	5	5	5
No. of combinations in the group	6	9	3

Table 6.51 Spearman rank correlation coefficient (R) values between ranks obtained due to change in PSIMAX, PCIMAX, PDIMAX values

	T1	T2	T3
T1	1.0000	0.9762	0.9286
T2		1.0000	0.9762
T3			1.0000

6.5.6.2 Multi Attribute Utility Theory (MAUT)

In the sensitivity analysis, the probability value of p' is varied from 0.5 to 1.0 with an increment of 0.05 (i.e., 0.50, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.0). A total of 11 combinations are evaluated and five groups of ranking are observed (denoted as S1, S2, S3, S4, S5) and these are presented in Table 6.52. It is observed that either group G7 or group G5 remains in the first place or the second place.

Table 6.52 Sensitivity on final ranks due to change in p' in MAUT methodology

	S1	S2	S3	S4	S5
G1	8	8	8	8	7
G2	5	5	6	6	6
G3	7	6	4	5	8
G4	3	3	3	3	3
G5	2	2	1	2	2
G6	6	7	7	7	5
G7	1	1	2	1	1
G8	4	4	5	4	4
No. of combinations in the group	4	3	2	1	1

Spearman rank correlation coefficient values are determined between the ranks obtained due to change in p' values and presented in Table 6.53.

Table 6.53 Spearman rank correlation coefficient (R) values between ranks obtained due to change in p' in MAUT methodology

	S1	S2	S3	S4	S5
S1	1.0000	0.9762	0.8333	0.9286	0.9524
S2		1.0000	0.9048	0.9762	0.8809
S3			1.0000	0.9524	0.7143
S4				1.0000	0.8333
S5					1.0000

It is observed that the correlation values range from 0.7143 to 0.9762 (excluding the diagonals). High correlation value of 0.9762 is observed between S1 and S2, S2 and S4. Similarly, correlation value of 0.9524 is observed between S1 and S5, S3 and S4. The Spearman Correlation Coefficient value of 0.8333 is observed between S1 and S3 and S4 and S5 whereas it is 0.9286 between S1 and S4. The correlation between S2 and S3 is 0.9048 whereas it is 0.8809 between S2 and S5. Low correlation value of 0.7143 is observed between S3 and S5.

The value of each scaling constant is increased and then decreased as much as possible without changing the order of the criteria. For example, CPR is the second largest criterion with a scaling constant value of 0.4138. The adjacent values are 0.4926 (EI) and 0.3350 (CUW). Therefore two sensitivity runs are performed for this criterion (without changing the scaling constant values of other criteria) to investigate the influence of values up to 0.4925 and 0.3351 on the ranking respectively. This represents the range that maintains the same order. A similar analysis is also done for other criteria resulting in 12 sensitivity runs for each probability value p'. The scaling constants and its ranges are presented in Table 6.54.

Table 6.54 Values of scaling constants and their ranges in MAUT methodology

Criteria	Scaling Constants	Minimum	Maximum
EI (k_5)	0.4926	0.4139	-
CPR (k_6)	0.4138	0.3351	0.4925
CUW (k_3)	0.3350	0.3154	0.4137
PF (k_4)	0.3153	0.2365	0.3349
EC (k_7)	0.2364	0.2168	0.3152
TSI (k_2)	0.2167	0.0592	0.2363
LDW (k_1)	0.0591	-	0.2166

Analysis is performed for different probability values p' varying from 0.5 to 1.0 with an increment of 0.05. A total of 132 combinations (11 probability combinations $\times$ 12 scaling constant combinations) are evaluated. Seven groups of ranking are observed (denoted as T1, T2, T3, T4, T5, T6, T7) and presented in Table 6.55. It is observed that G5 occupies the first position whereas G7 occupies either the second or the third position.

Table 6.55 Sensitivity on final ranks due to change in values of scaling constants in MAUT methodology

	T1	T2	T3	T4	T5	T6	T7
G1	8	8	8	8	8	8	8
G2	5	4	4	5	6	4	4
G3	4	5	5	4	4	6	7
G4	3	3	2	2	3	3	3
G5	1	1	1	1	1	1	1
G6	7	7	7	7	7	7	6
G7	2	2	3	3	2	2	2
G8	6	6	6	6	5	5	5
No. of combinations in the group	60	32	23	11	3	2	1

Spearman rank correlation coefficient is computed between the ranks obtained in Table 6.55 and these are presented in Table 6.56.

Table 6.56 Spearman rank correlation coefficient (R) values between ranks obtained due to change in values of scaling constants

	T1	T2	T3	T4	T5	T6	T7
T1	1.0000	0.9762	0.9524	0.9762	0.9762	0.9286	0.8571
T2		1.0000	0.9762	0.9524	0.9286	0.9762	0.9286
T3			1.0000	0.9762	0.9048	0.9524	0.9048
T4				1.0000	0.9524	0.9048	0.8333
T5					1.0000	0.9048	0.8333
T6						1.0000	0.9762
T7							1.0000

It is observed that the correlation coefficient values are high between the combinations ranging from 0.8333 to 0.9762. High correlation coefficient value of 0.9762 is observed between T1, T2; T1, T4; T1, T5; T2, T3; T2, T6; T6, T7 whereas it is 0.9524 among T1, T3; T2, T4; T3, T6; T4, T5. Similarly, it is observed that correlation value between T1, T6; T2, T5; T2, T7 is 0.9286 and it is 0.9048 between T3, T5; T3, T7; T4, T6; T5, T6. Low correlation value of 0.8333 is observed between T4 and T7; T5 and T7 whereas it is 0.8571 between T1 and T7.

Effect of probability value p' on scaling constants and overall scaling constant values are also studied. It is observed from Table 6.57 that as probability p' values are increasing, the scaling constant values (k_1 to k_7) are also increasing keeping the order same. Conversely, the overall scaling constant value k is decreasing. It is also observed that for a probability p'=0.5, it shows the risk seeking attitude of the decision maker as k=0.7787. As probability p' is increasing from 0.55 to 1.0, it shows the risk aversive attitude of the decision maker with variation of k values from -0.0805 to -0.9953 (Goicoechea *et al*, 1982).

Table 6.57 Effect of p' values on scaling constant values

p'	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k
0.50	0.0294	0.1076	0.1663	0.1565	0.2446	0.2055	0.1174	0.7787
0.55	0.0388	0.1421	0.2196	0.2067	0.3230	0.2713	0.1550	-0.0805
0.60	0.0488	0.1789	0.2766	0.2603	0.4067	0.3416	0.1952	-0.5072
0.65	0.0591	0.2167	0.3350	0.3153	0.4926	0.4138	0.2364	-0.7288
0.70	0.0693	0.2542	0.3928	0.3697	0.5777	0.4853	0.2773	-0.8478
0.75	0.0792	0.2905	0.4490	0.4226	0.6603	0.5547	0.3169	-0.9135
0.80	0.0887	0.3251	0.5025	0.4729	0.7389	0.6207	0.3547	-0.9506
0.85	0.0975	0.3576	0.5527	0.5202	0.8128	0.6828	0.3901	-0.9718
0.90	0.1058	0.3880	0.5996	0.5644	0.8818	0.7407	0.4233	-0.9840
0.95	0.1135	0.4161	0.6431	0.6052	0.9457	0.7944	0.4539	-0.9911
1.0	0.1206	0.4421	0.6832	0.6430	1.0000	0.8439	0.4823	-0.9953

6.5.6.3 Compromise Programming (CP)

The maximum and minimum value for each criterion from Table 6.35 (a) is included in the denominator as per Eq. 4.36 (b). L_p - metric and ranking pattern for p=1, 2, ∞ are calculated and it is presented in Table 6.58. It is observed that group G5 occupies the first position due to its low L_p - metric value for all p=1, 2, ∞. Spearman rank correlation coefficient between p=1 and p=2 is 0.6428 whereas it is 0.5238 between p=1 and p=∞. High correlation coefficient value of 0.9285 is observed between p=2 and p=∞.

Table 6.58 L_p - metric values and final ranks by CP methodology

Groups	p=1	p=2	p=∞
G1	8	5	4
G2	5	4	6
G3	3	2	2
G4	2	3	3
G5	1	1	1
G6	7	6	5
G7	4	8	8
G8	6	7	7

6.5.7 Guidelines for Improvement of Irrigation Subsystems

Based on the above three phase methodology, it is inferred that G5 (representing Parsoliya (IS4), Bhawarwad (IS8) irrigation subsystems) and G7 (representing Badliya (IS6), Karan Pur (IS11) irrigation subsystems) can be made pilot irrigation subsystems to formulate guidelines for other irrigation subsystems. This inference is based on the formulated payoff matrix, weights given by the decision maker, extensive sensitivity analysis and available data. However, these may vary depending on the weights and precise numerical values. The following are the guidelines for the improvement of other irrigation subsystems with reference to G5 and G7:

(i) Group G1 [Udpura (IS7), Khodan (IS16)]

It is observed that LDW (27) has low value when compared to group G5 (41) and group G7 (49). In order to improve LDW, the farmers' representing this group should be trained on the modern techniques of land leveling and shaping. Similarly, more focus is required on the performance criteria CPR and CUW that requires improvements as compared to that of G5 and G7. Different methods of increasing the crop productivity and judicious use of ground water in conjunction with surface water should be taught to the farmers' in the group G1 to improve its overall performance.

(ii) Group G2 [Arthuna (IS5), Asoda (IS15)]

It is inferred that the performance criteria LDW (34) and EC (37) are low when compared to group G5 and group G7. For group G5, LDW has a value of 41 whereas group G7 has a value of 49. Similarly, for EC, the values are 77 and 61 for group G5 and group G7. It is suggested that land development works need to be improved along with the environmental conservation in Arthuna (IS5) and Asoda (IS15) irrigation subsystems to perform better on par with groups G5 and G7.

(iii)Group G3 [Gopinath Ka Gara (IS3), Jagpura (IS10)]

Gopinath Ka Gara (IS3) and Jagpura (IS10) irrigation subsystems representing group G3 are observed to perform very low with respect to land development works, conjunctive use of water resources and participation of farmers' when compared with groups G5 and G7. More focus on the above mentioned performance criteria would improve these irrigation subsystems.

(iv)Group G4 [Narwali (IS9), Ganoda (IS12)]

The performance of irrigation subsystems representing group G4 is better with respect to most of the criteria when compared with groups G5 and G7 except for CUW and EC which has a value of 47 and 46 respectively. More emphasis on necessity of conjunctive use of water resources and environmental conservation can make Narwali (IS9) and Ganoda (IS12) irrigation subsystems, a better one. In this process, G5 and G7 can also be improved based on G4, if situation arises.

(v) Group G6 [Loharia (IS13), Badi Saderi (IS14)]

It is observed that motivation for farmers' participation and awareness on conjunctive use of water resources is less in group G6 when compared with G5 and G7. Similarly, the crop productivity in group G6 can be improved for better performance of Loharia (IS13) and Badi Saderi (IS14) irrigation subsystems.

(vi)Group G8 [Banka (IS1), Chhich (IS2)]

Banka (IS1) and Chhich (IS2) irrigation subsystems representing group G8 have average values for LDW (36), CUW (39), EI (43) and CPR (45) as compared to the group G5 and group G7. More focus on these low performing criteria would improve the performance of these irrigation subsystems similar to groups G5 and G7.

The conclusions emanated from Part 2 of the study which inferred G5 (representing Parsoliya (IS4), Bhawarwad (IS8) irrigation subsystems) and G7 (representing Badliya (IS6), Karan Pur (IS11) irrigation subsystems) as potential irrigation subsystems can be utilized by the project officials for further in depth investigations. Efforts are already in progress to collect more precise numerical data which may change the preference of the irrigation subsystem(s). However, the proposed methodology remains same..

The next chapter presents the summary and conclusions inferred from the above studies.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The present investigation consists of two parts. The first part dealt with irrigation planning problem that consists of single objective of annual net benefits, while the second part dealt with the performance evaluation aspects of irrigation subsystems. The methodologies developed are applied to an existing Mahi Bajaj Sagar Project (MBSP), Rajasthan, India that can serve as a model for further improvements.

Farmers' interviews have been conducted using structured questionnaire to enable the analysis of the existing water management practices, to know the constraints in utilizing the resources in the project and to develop the basis for systematic approach for performance improvements. Opinion of 208 farmers' belonging to sixteen irrigation subsystems of MBSP was considered. Discussion with project officials at various levels and information from reports also helped to understand the system characteristics and identify the performance criteria that are relevant for the present study.

Part 1 of the study is related to the reservoir operation for irrigation planning aspects. The developed planning model (with objective of annual net benefits) is subjected to continuity equation, land availability, crop diversification considerations, upstream and downstream requirements, evaporation losses, surface and ground water availability, limitations on reservoir and canal capacities. Uncertainty in inflows is also considered in the present study. Two types of scenarios are considered i.e., Scenario 1 and Scenario 2.

In Scenario 1, the lower and upper limits are based on cropping intensity of 89% i.e., 89% of 57,531 ha and 89% of 80,000 ha with existing live storage of reservoir 1829.27 Mm^3. In Scenario 2, lower and upper limits are 89% of 57, 531 ha and 89% of 1,23,500 ha with live storage of 2000 Mm^3. Interactive computer programs are developed for Real-coded Genetic Algorithm (RGA), Differential Evolution (DE), Simulated Annealing (SA), Simulated Quenching (SQ) and LINDO software for Linear Programming (LP). Penalty function approach is used to convert constrained problem into unconstrained problem for further use in all four non-traditional optimization techniques. Comparative analysis of various characteristics of these four non-traditional optimization techniques is also made. Similarly, annual net benefits, cropping pattern, reservoir storage, release and ground water pumping policies resulting from the above analysis are also compared. Extensive sensitivity analysis is performed for each non-traditional optimization technique to check the robustness and ascertain the appropriate parameters.

Part 2 of the investigation dealt with performance evaluation studies of sixteen irrigation subsystems of MBSP. Seven performance criteria namely, land development works, timely supply of inputs, conjunctive use of water resources, participation of farmers', economic impact, crop productivity and environmental conservation are considered in evaluating the irrigation subsystems. Weights of the criteria are obtained by Analytic Hierarchy Process (AHP). Three phase methodology consisting of formulating payoff matrix, grouping and ranking the irrigation subsystems was employed. Kohonen Artificial Neural Networks (KANN) methodology is used to group the irrigation subsystems. Sensitivity analysis is performed for the number of groups, different epochs and various learning rates to choose the appropriate parameters for the KANN. Three Multicriterion decision making (MCDM) techniques, namely, Multicriterion Q-Analysis-2, Multi Attribute Utility Theory and Compromise Programming are implemented to rank the groups that emanated after KANN classification. Interactive computer programs are developed for the above MCDM techniques. Spearman Rank Correlation coefficient values are computed between the ranks obtained by various MCDM techniques. Sensitivity analysis is performed for the MCDM techniques to assess the effect of the parameters on the ranking pattern. The following conclusions are drawn from the two parts of the study.

Part 1: Optimal Reservoir Operation for Irrigation Planning

Scenario 1

1. It is observed that the values of net benefits are Rs.113.15 crores, Rs.111.65 crores, Rs.112.68 crores, Rs.100.27 crores and Rs.99.77 crores for LP, RGA, DE, SA and SQ respectively.
2. It is observed that the net benefits are varying from Rs.110.86 crores (DE/best/1/exp strategy) to Rs.112.71 crores (DE/rand/2/bin strategy) with a range of Rs.1.85 crores.
3. The ratio of total area to lower limit (in percentage) for MBSP is 132.28, 131.20, 131.99, 117.67 and 118.55 for LP, RGA, DE, SA and SQ respectively.
4. It is observed from the extensive sensitivity analysis that RGA, DE, SA and SQ yielded same results as that of LP for the optimal set of parameters. Salient observations emanated from the sensitivity analysis studies are:
   (i) It is observed that the annual net benefits are Rs.113.15 crores resulting from total irrigated area of 67736 ha. Ratio of annual net benefits to irrigated area is Rs.16705 per hectare.
   (ii) The maximum live storage is observed in the month of November whereas significant overflows of around 424 Mm^3 is observed in the month of October. Contrary, empty storage is observed in the month of August.
   (iii) It is observed that the ground water is utilized to its maximum potential of 31.07 Mm^3. Out of which 79 % of utilization is in the month of July.
   (iv) The annual releases into LMC, RMC and BC are 303.65 Mm^3, 265.50 Mm^3 and 15.63 Mm^3 respectively. Monthly releases into the canal are always less than their maximum capacity.
   (v) Even though all the four non-traditional techniques yields same result pattern, their CPU time requirements are not same. CPU time requirements in the order of decreasing trend are SA, SQ, RGA and DE. Similar observation is made for Scenario 2.

(vi)Out of the ten DE strategies employed, DE/rand-to-best/1/bin strategy is found to be advantageous due to its faster convergence as compared to other nine DE strategies which is evident from their CPU time requirements.

Scenario 2

5. It is observed that the values of net benefits are Rs.163.20 crores, Rs.162.22 crores, Rs.162.74 crores, Rs.140.31 crores and Rs.147.50 crores for LP, RGA, DE, SA and SQ respectively.
6. The variations of net benefits are significant and are varying from Rs.157.54 crores (DE/rand/2/exp strategy) to Rs.162.97 crores (DE/rand-to-best/1/exp strategy) with a range of Rs.5.43 crores for the ten DE strategies.
7. The ratio of total area to lower limit (in percentage) for MBSP is 187.09, 186.54, 186.77, 163.35 and 169.34 for LP, RGA, DE, SA and SQ respectively.
8. It is observed from the extensive sensitivity analysis that RGA, DE, SA and SQ yielded same results as that of LP for the optimal set of parameters. Salient observations emanated from the sensitivity analysis studies are:

(i) It is observed that the annual net benefits are Rs.163.20 crores resulting from total irrigated area of 95798 ha. Ratio of annual net benefits to irrigated area is Rs.17036 per hectare. It is 2 % more as compared to Scenario 1.

(ii) The maximum live storage is observed in the month of November whereas significant overflows of around 213 Mm^3 is observed in the month of October. Reasonable amount of water is available in the month of August.

(iii)It is observed that the ground water withdrawal is not required which may be due to the availability of sufficient water in the reservoir for irrigation. This reduces the burden on the dwindling ground water resources to a greater extent which is a boon to drought prone state like Rajasthan.

(iv)The annual releases into LMC, RMC and BC are 351.44 Mm^3, 477.07 Mm^3 and 27.26 Mm^3 respectively. It is observed that the monthly releases to RMC reach its maximum capacity of 78.89 Mm^3 during February.

(v) Out of the ten DE strategies employed, DE/best/1/bin strategy is found to be advantageous due to its faster convergence as compared to other nine DE strategies which is evident from their CPU time requirements.

9. It is observed that RGA and DE can be considered as one group due to their similar result pattern, robustness, faster convergence as evident from their low CPU time requirements.
10. It is observed that SA and SQ can be considered as another group due to their abnormal result pattern, slow convergence as evident from their high CPU time requirements. This necessitates in depth analysis which is targeted for further study.
11. Comparative assessment of four non-traditional optimization techniques identified two groups from the study i.e., RGA, DE and SA, SQ. This supports the theory that RGA and DE are population based search techniques whereas SA and SQ are point by point search techniques.
12. It is observed that RGA and DE can be considered as alternative methodologies due to their similar result pattern as compared to LP. This is evident from the extensive sensitivity analysis studies performed for both scenarios.

PART 2: PERFORMANCE EVALUATION STUDIES

13. Three phase methodology employed in the present study is found to be useful.
14. It is observed that G7 (representing Badliya, Karan Pur irrigation subsystems) and G5 (representing Parsoliya, Bhawarwad irrigation subsystems) can be made pilot irrigation subsystems to formulate guidelines for other irrigation subsystems.
15. Potentiality of KANN methodology is explored to group the irrigation subsystems for performance evaluation studies.
16. It is observed from KANN methodology that square error value is decreasing from group 4 to group 8.
17. Economic impact and crop productivity contributes approximately 55% of the importance that affects ranking pattern where as other criteria are around 45%.
18. Effect of slicing thresholds and PCIMAX, PSIMAX and PDIMAX have a significant effect on the ranking pattern.
19. It is observed from MAUT analysis that as probability p' values are increasing, the scaling constant values (k_1 to k_7) are also increasing and conversely, the overall scaling constant value k is decreasing indicating the risk aversive attitude of the decision maker.

CONTRIBUTIONS FROM THE STUDY

1. Real-coded Genetic Algorithm with simulated binary crossover and parameter-based mutation is used for the first time in Irrigation Planning context.
2. Differential Evolution is used for the first time in the context of Irrigation Planning.
3. Simulated Quenching is used for the first time in the context of Irrigation Planning.
4. First application of Kohonen Artificial Neural Networks for grouping irrigation subsystems in performance evaluation studies.
5. First complete application of advanced modeling techniques and Multicriterion Decision Making for the real world planning problem of Mahi Bajaj Sagar Project, Rajasthan, India.

SCOPE FOR FURTHER WORK

1. Irrigation planning model employed in the present study can be extended in the multiobjective framework using non-traditional optimization techniques.
2. More DE strategies can be formulated.
3. Simulated Annealing and Simulated Quenching can be validated for more case studies for further improvements.
4. Optimal set of parameters for various non-traditional optimization techniques can be determined using suitable optimization technique.
5. More farmers, officials, experts and weight sets can be considered in the decision making process.
6. More performance criteria can be targeted with precise numerical values.
7. Optimal number of groups in KANN can be determined using Dunn's index.

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APPENDIX A

FARMERS' RESPONSE SURVEY QUESTIONNAIRE

(Translated from the Hindi Language)

1. GENERAL DETAILS, LOCATION AND WATER SOURCE

Farmer's Name: ______________________

Name of the Village: ______________________

Name of Irrigation Subsystem: ______________________

Area: __________

Reach: Head ☐ Middle ☐ Tail ☐

Most of irrigation water is taken from

- ➢ Authorized off take ☐
- ➢ Re-use from drains ☐
- ➢ Wells ☐
- ➢ Other ______________ ☐

2. CROPPING INTENSITY AND YIELDS

- What are the Crops that are grown in each season and status of yields from them?

Crops	Kharif	Rabi	Other	Very Good	Good	Average	Satis-factory	Unsatis-factory
Maize								
Paddy								
Cotton								
Pulses								
Sugarcane								
Zaid								

Wheat								
Barley								
Gram								
Barseen								
Mustard								
Fruits & Veg.								
Other								

3. WATER SUPPLY

- Is the rainfall amount
  - More than Average ☐
  - Average ☐
  - Less than Average ☐
- Are you of the opinion that canal water cost is reasonable?

  Yes ☐ No ☐

4. MISCELLANEOUS

- Are you interested to participate in O & M works?

  Yes ☐ No ☐
- Has farmers' group been formed at the pipe/distributory level?

  Yes ☐ No ☐
- Are you aware of the critical periods of the crops grown by you?

  Yes ☐ No ☐
- Are you aware of the crop and input price policies of the Government?

  Yes ☐ No ☐
- Are you satisfied with the quality of water being supplied to you?

  Yes ☐ No ☐
- Would you say that this irrigation project has benefited the farmers' in the project area

  By way of increasing agricultural production Yes ☐ No ☐

  By way of increasing income Yes ☐ No ☐

  By way of getting employment Yes ☐ No ☐

5. **ASSESSMENT OF PERFORMANCE CRITERIA**

Component	Very Good	Good	Average	Satisfac-tory	Unsatisfac-tory
Change in irrigated area (as compared to pre-project era)					
Change in wages of agricultural labourers (as compared to pre-project era)					
Crop productivity/unit of water					
Crop diversification					
Status of land leveling and development work					
Supply of other inputs					
Status of conjunctive use of water resources					
Farmers' participation					
Economic impact of irrigated agriculture					
Crop Productivity/ha					
Environmental conservation					

- Any other information that you want to add.

Date: ______________

APPENDIX B

SUMMARY OF FARMERS' RESPONSE SURVEY FOR SIXTEEN IRRIGATION SUBSYSTEMS

Irrigation Subsystem Name: Banka		Head		Middle		Tail	
Number of Farmers'	Total: 15	4		5		6	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	4		5		6	
	• Reuse of Drains	-		-		-	
	• Wells	2		4		5	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		1	
	• Average	4		4		5	
	• Less than Average	-		1		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	4	-	5	-	6	-
4.	Are you interested to participate in O & M works?	4	-	5	-	6	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	4	-	5	-	6
6.	Are you aware of the critical periods of the crops grown by you?	4	-	5	-	6	-
7.	Are you aware of the crop and input price policies of the Government?	3	1	5	-	6	-
8.	Are you satisfied with the quality of water being supplied to you?	4	-	5	-	6	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	4	-	5	-	5	1
	• By way of increasing income	4	-	4	1	6	-
	• By way of getting employment	4	-	4	1	6	-

Continued...

Irrigation Subsystem Name: Chhich		Head		Middle		Tail	
Number of Farmers'	Total: 14	6		5		3	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	6		5		3	
	• Reuse of Drains	-		-		-	
	• Wells	4		-		1	
	• Others	-		1		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	6		4		3	
	• Less than Average	-		1		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	6	-	4	1	3	-
4.	Are you interested to participate in O & M works?	6	-	5	-	3	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	6	-	5	-	3
6.	Are you aware of the critical periods of the crops grown by you?	6	-	5	-	3	-
7.	Are you aware of the crop and input price policies of the Government?	6	-	5	-	3	-
8.	Are you satisfied with the quality of water being supplied to you?	6	-	5	-	3	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	5	1	5	-	2	1
	• By way of increasing income	6	-	4	1	3	-
	• By way of getting employment	6	-	5	-	3	-

Continued...

Irrigation Subsystem Name: Gopinath Ka Gara		Head		Middle		Tail	
Number of Farmers'	Total: 11	4		4		3	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	4		4		3	
	• Reuse of Drains	-		-		-	
	• Wells	3		2		3	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	4		4		3	
	• Less than Average	-		1		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	4	-	4	-	2	1
4.	Are you interested to participate in O & M works?	4	-	4	-	3	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	4	-	4	-	3
6.	Are you aware of the critical periods of the crops grown by you?	4	-	4	-	3	-
7.	Are you aware of the crop and input price policies of the Government?	3	1	4	-	3	-
8.	Are you satisfied with the quality of water being supplied to you?	4	-	4	-	3	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	3	1	3	1	2	1
	• By way of increasing income	4	-	3	1	3	-
	• By way of getting employment	4	-	4	-	3	-

Continued...

Irrigation Subsystem Name: Parsoliya			Head		Middle		Tail	
Number of Farmers'		Total: 14	5		4		5	
S.No.	Questions							
1.	Most of the Irrigation water is taken from							
	• Authorized Off take		5		4		5	
	• Reuse of Drains		-		-		-	
	• Wells		1		1		3	
	• Others		-		-		-	
2.	Is the rainfall amount							
	• More than Average		-		-		-	
	• Average		4		3		5	
	• Less than Average		1		1		-	
			Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?		5	-	4	-	5	-
4.	Are you interested to participate in O & M works?		5	-	4	-	5	-
5.	Have farmers' group been formed at the pipe/distributory level?		-	5	-	4	-	5
6.	Are you aware of the critical periods of the crops grown by you?		5	-	4	-	5	-
7.	Are you aware of the crop and input price policies of the Government?		5	-	4	-	4	1
8.	Are you satisfied with the quality of water being supplied to you?		5	-	4	-	5	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area							
	• By way of increasing agricultural production		4	1	4	-	3	2
	• By way of increasing income		5	-	2	2	3	2
	• By way of getting employment		5	-	4	-	4	1

Continued...

Irrigation Subsystem Name: Arthuna			Head		Middle		Tail	
Number of Farmers'		Total: 14	4		5		5	
S.No.	Questions							
1.	Most of the Irrigation water is taken from							
	• Authorized Off take		4		5		5	
	• Reuse of Drains		-		-		-	
	• Wells		-		2		1	
	• Others		-		-		-	
2.	Is the rainfall amount							
	• More than Average		-		-		-	
	• Average		4		4		5	
	• Less than Average		-		1		-	
			Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?		4	-	5	-	5	-
4.	Are you interested to participate in O & M works?		4	-	5	-	5	-
5.	Have farmers' group been formed at the pipe/distributory level?		-	4	-	5	-	5
6.	Are you aware of the critical periods of the crops grown by you?		4	-	5	-	5	-
7.	Are you aware of the crop and input price policies of the Government?		4	-	4	1	5	-
8.	Are you satisfied with the quality of water being supplied to you?		4	-	5	-	5	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area							
	• By way of increasing agricultural production		2	2	3	2	3	2
	• By way of increasing income		3	1	5	-	4	1
	• By way of getting employment		4	-	5	-	5	1

Continued...

Irrigation Subsystem Name: Badliya		Head		Middle		Tail	
Number of Farmers'	Total: 12	6		-		6	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	6		-		6	
	• Reuse of Drains	-		-		1	
	• Wells	3		-		2	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	6		-		6	
	• Less than Average	-		-		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	6	-	-	-	5	1
4.	Are you interested to participate in O & M works?	6	-	-	-	6	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	6	-	-	-	6
6.	Are you aware of the critical periods of the crops grown by you?	6	-	-	-	6	-
7.	Are you aware of the crop and input price policies of the Government?	6	-	-	-	5	1
8.	Are you satisfied with the quality of water being supplied to you?	6	-	-	-	6	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	2	-	-	-	5	1
	• By way of increasing income	6	-	-	-	6	-
	• By way of getting employment	6	-	-	-	6	-

Continued...

Irrigation Subsystem Name: Udpura			Head		Middle		Tail	
Number of Farmers'		Total: 12	6		-		6	
S.No.	Questions							
1.	Most of the Irrigation water is taken from							
	• Authorized Off take		6		-		6	
	• Reuse of Drains		-		-		-	
	• Wells		3		-		2	
	• Others		-		-		-	
2.	Is the rainfall amount							
	• More than Average		-		-		-	
	• Average		6		-		5	
	• Less than Average		-		-		1	
			Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?		6	-	-	-	6	-
4.	Are you interested to participate in O & M works?		6	-	-	-	6	-
5.	Have farmers' group been formed at the pipe/distributory level?		-	6	-	-	-	6
6.	Are you aware of the critical periods of the crops grown by you?		6	-	-	-	6	-
7.	Are you aware of the crop and input price policies of the Government?		5	1	-	-	6	-
8.	Are you satisfied with the quality of water being supplied to you?		6	-	-	-	6	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area							
	• By way of increasing agricultural production		5	1	-	-	4	2
	• By way of increasing income		6	-	-	-	6	-
	• By way of getting employment		6	-	-	-	6	-

Continued...

Irrigation Subsystem Name: Bhawarwad		Head		Middle		Tail	
Number of Farmers'	Total: 12	6		-		6	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	6		-		6	
	• Reuse of Drains	-		-		-	
	• Wells	1		-		4	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	6		-		6	
	• Less than Average	-		-		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	6	-	-	-	6	-
4.	Are you interested to participate in O & M works?	6	-	-	-	6	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	6	-	-	-	6
6.	Are you aware of the critical periods of the crops grown by you?	6	-	-	-	5	1
7.	Are you aware of the crop and input price policies of the Government?	6	-	-	-	6	-
8.	Are you satisfied with the quality of water being supplied to you?	5	1	-	-	6	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	5	1	-	-	6	-
	• By way of increasing income	6	-	-	-	5	1
	• By way of getting employment	6	-	-	-	6	-

Continued...

Irrigation Subsystem Name: Narwali		Head		Middle		Tail	
Number of Farmers'	Total: 16	6		5		5	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	6		5		5	
	• Reuse of Drains	-		1		-	
	• Wells	4		2		2	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	6		5		5	
	• Less than Average	-		-		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	6	-	5	-	5	-
4.	Are you interested to participate in O & M works?	6	-	5	-	5	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	6	-	5	-	5
6.	Are you aware of the critical periods of the crops grown by you?	6	-	5	-	5	-
7.	Are you aware of the crop and input price policies of the Government?	6	-	5	-	5	-
8.	Are you satisfied with the quality of water being supplied to you?	6	-	5	-	5	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	6	-	3	2	4	1
	• By way of increasing income	6	-	5	-	5	-
	• By way of getting employment	6	-	5	-	5	-

Continued...

Irrigation Subsystem Name: Jagpura		Head		Middle		Tail	
Number of Farmers'	Total: 12	4		4		4	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	4		4		4	
	• Reuse of Drains	-		-		-	
	• Wells	3		1		3	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	4		4		4	
	• Less than Average	-		-		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	4	-	4	-	4	-
4.	Are you interested to participate in O & M works?	4	-	4	-	4	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	4	-	4	-	4
6.	Are you aware of the critical periods of the crops grown by you?	3	1	4	-	4	-
7.	Are you aware of the crop and input price policies of the Government?	-	4	-	4	-	4
8.	Are you satisfied with the quality of water being supplied to you?	4	-	4	-	4	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	3	1	4	-	3	1
	• By way of increasing income	4	-	3	1	4	-
	• By way of getting employment	4	-	4	-	4	-

Continued...

Irrigation Subsystem Name: Karanpur		Head		Middle		Tail	
Number of Farmers'	Total: 14	4		5		5	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	4		5		5	
	• Reuse of Drains	-		-		-	
	• Wells	2		1		4	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	3		5		5	
	• Less than Average	1		-		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	4	-	5	-	5	-
4.	Are you interested to participate in O & M works?	4	-	5	-	5	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	4	-	5	-	5
6.	Are you aware of the critical periods of the crops grown by you?	4	-	5	-	5	-
7.	Are you aware of the crop and input price policies of the Government?	4	-	4	1	5	-
8.	Are you satisfied with the quality of water being supplied to you?	4	-	5	-	5	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	2	-	4	1	4	1
	• By way of increasing income	4	-	4	1	5	-
	• By way of getting employment	4	-	5	-	5	-

Continued...

Irrigation Subsystem Name: Ganoda			Head		Middle		Tail	
Number of Farmers'		Total: 15	5		5		5	
S.No.	Questions							
1.	Most of the Irrigation water is taken from							
	• Authorized Off take		5		5		5	
	• Reuse of Drains		-		-		-	
	• Wells		3		1		1	
	• Others		-		-		-	
2.	Is the rainfall amount							
	• More than Average		-		-		-	
	• Average		5		5		5	
	• Less than Average		-		-		-	
			Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?		5	-	5	-	5	-
4.	Are you interested to participate in O & M works?		5	-	5	-	5	-
5.	Have farmers' group been formed at the pipe/distributory level?		-	5	-	5	-	5
6.	Are you aware of the critical periods of the crops grown by you?		5	-	5	-	5	-
7.	Are you aware of the crop and input price policies of the Government?		5	-	4	1	5	-
8.	Are you satisfied with the quality of water being supplied to you?		5	-	5	-	5	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area							
	• By way of increasing agricultural production		4	1	5	-	4	1
	• By way of increasing income		5	-	5	-	5	-
	• By way of getting employment		5	-	5	-	5	-

Continued...

Irrigation Subsystem Name: Loharia			Head		Middle		Tail	
Number of Farmers'		Total: 11	5		3		3	
S.No.	Questions							
1.	Most of the Irrigation water is taken from							
	• Authorized Off take		5		3		3	
	• Reuse of Drains		-		-		-	
	• Wells		4		-		1	
	• Others		-		-		-	
2.	Is the rainfall amount							
	• More than Average		-		-		-	
	• Average		5		3		3	
	• Less than Average		-		-		-	
			Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?		5	-	3	-	3	-
4.	Are you interested to participate in O & M works?		5	-	3	-	3	-
5.	Have farmers' group been formed at the pipe/distributory level?		-	5	-	3	-	3
6.	Are you aware of the critical periods of the crops grown by you?		4	1	3	-	3	-
7.	Are you aware of the crop and input price policies of the Government?		5	-	2	1	3	-
8.	Are you satisfied with the quality of water being supplied to you?		5	-	3	-	3	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area							
	• By way of increasing agricultural production		5	-	2	1	3	-
	• By way of increasing income		5	-	3	-	3	-
	• By way of getting employment		5	-	3	-	3	-

Continued...

Irrigation Subsystem Name: Badi Saderi			Head		Middle		Tail	
Number of Farmers'		Total: 11	6		-		5	
S.No.	Questions							
1.	Most of the Irrigation water is taken from							
	• Authorized Off take		6		-		5	
	• Reuse of Drains		-		-		-	
	• Wells		5		-		2	
	• Others		-		-		-	
2.	Is the rainfall amount							
	• More than Average		-		-		-	
	• Average		6		-		5	
	• Less than Average		-		-		-	
			Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?		6	-	-	-	5	-
4.	Are you interested to participate in O & M works?		6	-	-	-	5	-
5.	Have farmers' group been formed at the pipe/distributory level?		-	6	-	-	-	5
6.	Are you aware of the critical periods of the crops grown by you?		6	-	-	-	5	-
7.	Are you aware of the crop and input price policies of the Government?		6	-	-	-	5	-
8.	Are you satisfied with the quality of water being supplied to you?		6	-	-	-	5	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area							
	• By way of increasing agricultural production		5	1	-	-	5	-
	• By way of increasing income		6	-	-	-	5	-
	• By way of getting employment		6	-	-	-	5	-

Continued...

Irrigation Subsystem Name: Udpura		Head		Middle		Tail	
Number of Farmers'	Total: 11	5		-		6	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	5		-		6	
	• Reuse of Drains	-		-		-	
	• Wells	1		-		4	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	5		-		6	
	• Less than Average	-		-		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	5	-	-	-	6	-
4.	Are you interested to participate in O & M works?	5	-	-	-	6	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	5	-	-	-	6
6.	Are you aware of the critical periods of the crops grown by you?	5	-	-	-	6	-
7.	Are you aware of the crop and input price policies of the Government?	5	-	-	-	6	-
8.	Are you satisfied with the quality of water being supplied to you?	5	-	-	-	6	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	3	2	-	-	6	-
	• By way of increasing income	4	1	-	-	6	-
	• By way of getting employment	5	-	-	-	6	-

Continued...

Irrigation Subsystem Name: Khodan		Head		Middle		Tail	
Number of Farmers'	Total: 14	6		4		4	
S.No.	Questions						
1.	Most of the Irrigation water is taken from						
	• Authorized Off take	6		4		4	
	• Reuse of Drains	-		-		-	
	• Wells	2		3		-	
	• Others	-		-		-	
2.	Is the rainfall amount						
	• More than Average	-		-		-	
	• Average	6		4		4	
	• Less than Average	-		-		-	
		Yes	No	Yes	No	Yes	No
3.	Are you of the opinion that canal water cost is reasonable?	6	-	4	-	4	-
4.	Are you interested to participate in O & M works?	6	-	4	-	4	-
5.	Have farmers' group been formed at the pipe/distributory level?	-	6	-	4	-	4
6.	Are you aware of the critical periods of the crops grown by you?	6	-	3	1	4	-
7.	Are you aware of the crop and input price policies of the Government?	6	-	4	-	4	-
8.	Are you satisfied with the quality of water being supplied to you?	6	-	4	-	4	-
9.	Would you say that this irrigation project has benefited the farmers' in the project area						
	• By way of increasing agricultural production	6	-	3	1	4	-
	• By way of increasing income	6	-	4	-	3	1
	• By way of getting employment	6	-	4	-	4	-

APPENDIX C

PSEUDO CODE AND FLOW CHART OF THE NON-TRADITIONAL OPTIMIZATION TECHNIQUES

C-1 PSEUDO CODE OF REAL-CODED GENETIC ALGORITHM

```
/*Initialize zero'th generation and global parameters*/
initialize()
{
  float u;
  int k,k1,i,j,j1,stop;
  double temp[MAXVECSIZE],coef;
  unsigned mask=1,nbytes;

  randomize();
  app_initialize();
  oldpop = (INDIVIDUAL *)malloc(pop_size*sizeof(INDIVIDUAL));
  newpop = (INDIVIDUAL *)malloc(pop_size*sizeof(INDIVIDUAL));
  if (oldpop == NULL) nomemory("oldpop in initialize()");
  if (newpop == NULL) nomemory("newpop in initialize()");

  chromsize = (lchrom/UINTSIZE);
  if(lchrom%UINTSIZE) chromsize++;
  nbytes = chromsize*sizeof(unsigned);
  for(j = 0; j < pop_size; j++)
  {
    if((oldpop[j].chrom = (unsigned *) malloc(nbytes)) == NULL)
      nomemory("oldpop chromosomes");

    if((newpop[j].chrom = (unsigned *) malloc(nbytes)) == NULL)
      nomemory("newpop chromosomes");
  }
  if((best_ever.chrom = (unsigned *) malloc(nbytes)) == NULL)
    nomemory("best_ever chromosomes");

  for (k=0; k<= pop_size-1; k++)
  {
    oldpop[k].parent1 = oldpop[k].parent2 = 0;
    for (j=num_discr_var; j<=num_var-1; j++)
```

```
    {
      u = randomperc();
      oldpop[k].x[j] = x_lower[j] * (1-u) + x_upper[j] * u;
    }
    for(k1 = 0; k1 < chromsize; k1++)
    {
        oldpop[k].chrom[k1] = 0;
        if(k1 == (chromsize-1))
           stop = lchrom - (k1*UINTSIZE);
        else
           stop = UINTSIZE;
        /* A fair coin toss */
        for(j1 = 1; j1 <= stop; j1++)
        {
          if(flip(0.5))
            oldpop[k].chrom[k1] = oldpop[k].chrom[k1]|mask;
          if (j1 != stop) oldpop[k].chrom[k1] = oldpop[k].chrom[k1]<<1;
        }
    }
  }
  no_xover = no_mutation = 0;
  copy_individual(&oldpop[0],&best_ever);
  decode_string(&best_ever);
  best_ever.obj = objective(best_ever.x);

}

/*Generation of New Population through Selection, Xover & Mutation*/
generate_new_pop()
{
  int k,mate1,mate2;
  app_computation();
    for (k=0; k<= pop_size-1; k +=2)
  {
   switch (s_strategy)
   {
   mate1 = tour_select(); mate2 = tour_select(); break;
   }
   switch( x_strategy)
   {
    case ONESITE :  cross_over_1_site(mate1,mate2,k,k+1); break;
    case UNIF : cross_over_unif(mate1,mate2,k,k+1); break;
    case ONLINE: cross_over_line(mate1,mate2,k,k+1); break;
   }
   mutation(&newpop[k]);
   mutation(&newpop[k+1]);
```

```
    newpop[k].parent1 = newpop[k+1].parent1 = mate1+1;
    newpop[k].parent2 = newpop[k+1].parent2 = mate2+1;
  }
}
```

/*Creates two children from parents p1 and p2, stores them in addresses pointed by c1 and c2. low and high are the limits for x values and rand_var is the random variable used to create children points */

```
create_children(p1,p2,c1,c2,low,high,rand_var)
float p1,p2,*c1,*c2,low,high,*rand_var;
{
  float difference,x_mean,beta;
  float u,distance,umax,temp,alpha;
  int flag;
  if (c1 == NULL) error_ptr_null("c1 in create_children");
  if (c2 == NULL) error_ptr_null("c2 in create_children");
  if (rand_var == NULL) error_ptr_null("rand_var in create_children");
  flag = 0;
  if( p1 > p2) { temp = p1; p1 = p2; p2 = temp; flag = 1; }
  x_mean = ( p1 + p2) * 0.5;
  difference = p2 - p1;
  if( (p1-low) < (high-p2) )
       distance = p1-low;
  else
       distance = high-p2;
  if (distance < 0.0) distance = 0.0;
  if (RIGID && (difference > EPSILON))
  {
   alpha = 1.0 + (2.0*distance/difference);
   umax = 1.0 - (0.5 / pow((double)alpha,(double)(n_distribution_c+1.0)));
   *rand_var = umax * randomperc();
  }
  else *rand_var = randomperc();
  beta = get_beta(*rand_var);
  if (fabs(difference*beta) > INFINITY) beta = INFINITY/difference;
  *c2 = x_mean + beta * 0.5 * difference;
  *c1 = x_mean - beta * 0.5 * difference;
  if (flag == 1) { temp = *c1; *c1 = *c2; *c2 = temp; }
}
/*CROSS - OVER, each variable is crossed over with a probability, each time generating
a new random beta*/
cross_over_unif(first,second,childno1,childno2)
int first,second,childno1,childno2;
{
  float difference,x_mean,beta;
```

```
  float u = 0.0;
  int site,k;

  if (flip(p_xover))  /* Cross over has to be done */
  {
   no_xover++;
   if (REALGA)
   {
    for (site = num_discr_var; site<=num_var-1; site++)
    {
     if(flip(0.5) || (num_var==1))
     {
      create_children(oldpop[first].x[site],oldpop[second].x[site],
              &(newpop[childno1].x[site]),&(newpop[childno2].x[site]),
              x_lower[site],x_upper[site],&u);
     }
     else
     {
        newpop[childno1].x[site] = oldpop[first].x[site];
        newpop[childno2].x[site] = oldpop[second].x[site];
     }
    }         /* for loop */
        newpop[childno1].cross_var = newpop[childno2].cross_var = u;
   }          /* if REALGA    */
  }           /* Cross over done */

  else          /* Passing x-values straight */
  {
   for (site=0; site<=num_var-1; site++)
   {
    newpop[childno1].x[site] = oldpop[first].x[site];
    newpop[childno2].x[site] = oldpop[second].x[site];
   }
  }
}
```

/*Calculates beta value for given random number u (from 0 to 1). If input random numbers (u) are uniformly distributed for a set of inputs, this results in binary Probability distribution simulation in case of SBX*/

```
float get_beta(u)
float u;
{
  float beta;

  if (cross_type == BLX) return(2.0*u);
  if (1.0-u < EPSILON ) u = 1.0 - EPSILON;
  if ( u < 0.0) u = 0.0;
```

```
  if (u < 0.5) beta = pow(2.0*u,(1.0/(n_distribution_c+1.0)));
  else beta = pow( (0.5/(1.0-u)),(1.0/(n_distribution_c+1.0)));
  return beta;
}
/*For given u value such that  -1 <= u <= 1, this routine returns a value of delta from -1
to 1. Exact value of delta depends on specified n_distribution. This is called by
mutation()*/
float get_delta(u)
float u;
{
  float delta;
  int negative = FALSE;  /* Flag for negativeness of delta */

  if (cross_type == BLX) return(u);
  if(u <= -1.0) u = -1.0;
  if(u >1.0)  u =  1.0;
  if(u < 0.0)  {  u = -u;
             negative = TRUE;
           }
  delta = 1.0 - pow((1.0 - u),(1.0 / (n_distribution_m + 1.0)));
  if(negative)  return (-delta);
  else        return delta;

}
/*Mutation using polynomial probability distribution. Picks up a random site and
generates a random number u between -1 to 1, (or between minu to maxu in case of rigid
boundaries) and calls the routine get_delta() to calculate the actual shift of the value*/
mutation(indiv)
INDIVIDUAL  *indiv;
{
  float distance1,distance2,x,delta,minu,maxu,u;
  int k, site;

  if (indiv == NULL) error_ptr_null("indiv in mutation");
  if(flip (p_mutation) && REALGA)
  {
     site = rnd(num_discr_var,num_var - 1);
     no_mutation++;
     if(fabs(x_upper[site] -x_lower[site]) < EPSILON) return;

     /* calculation of bounds on delta */
     if(RIGID)
     { x = indiv->x[site];
      distance1 = x - x_lower[site];
      distance2 = x_upper[site] - x;
```

```
        delta = 2.0 * distance1 / (x_upper[site] - x_lower[site]);
        if (delta > 1.0)   delta = 1.0;
        minu = -1.0 + pow((1.0 - delta),(n_distribution_m + 1.0));

        delta = 2.0 * distance2 / (x_upper[site] - x_lower[site]);
        if (delta > 1.0)   delta = 1.0;
        maxu = 1.0 - pow((1.0 - delta),(n_distribution_m + 1.0));
        u = rndreal(minu,maxu);
      }
      else u = rndreal(-1.0,1.0);

      /* calculation of actual delta value */
      delta = get_delta(u) *  0.5 * (x_upper[site] - x_lower[site]);
      indiv->x[site] += delta;
  }   /* if flip() */
}

/*MAIN PROGRAM*/
main()
{
  input_parameters();
  fp_out = fopen("realga.out","w+");
  select_memory();
  initreport(fp_out);
  for (run = 1; run<= maxrun; run++)
   {
    gen_no = 0;
    initialize();
    for(gen_no = 1; gen_no<=max_gen; gen_no++)
        {
         generate_new_pop();
         temp = oldpop;
         oldpop = newpop;
         newpop = temp;
         report(fp_out,gen_no);
        };                  /* One GA run is over  */
    free_all();
   }              /* for loop of run  */

printf("\n Results are stored in file 'realga.out' ");
}

/*************** End of Main Program **************************/
```

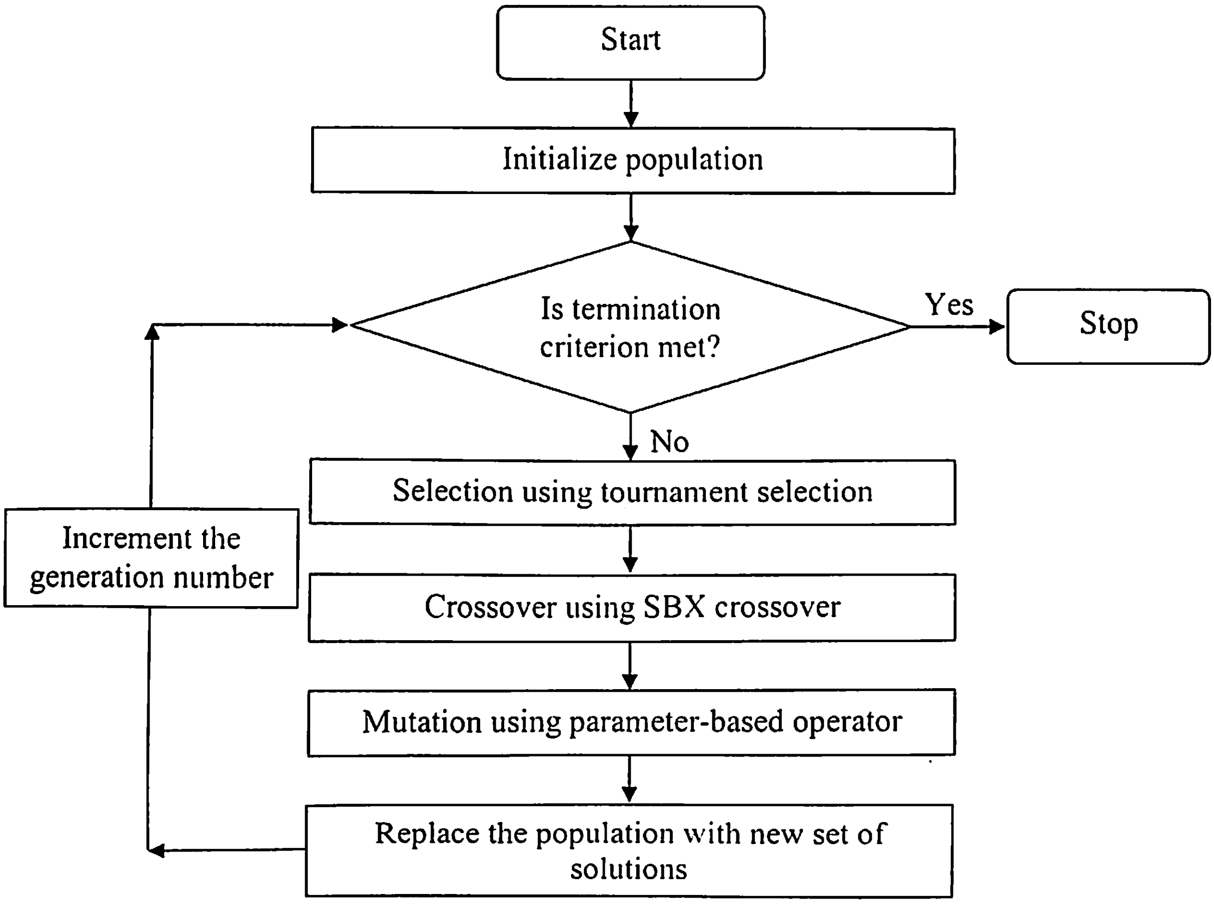

Fig. C-1 Flow chart of computer program for Real-coded Genetic Algorithms

C-2 PSEUDO CODE OF DIFFERENTIAL EVOLUTION

```
for(i=0;i<NP;i++)
{
        for(j=0;j<D;j++)
                x1[i][j]= xlow[j]+rnd_uni()*(xhigh[j]-xlow[j]);
        cost[i] = evaluate(x1[i]);
}
cmin = cost[0];
imin = 0;
for (i=1; i<NP; i++)
{
        if (cost[i]<cmin)
        {
                cmin = cost[i];
                imin = i;
        }
}
copyPoint(best,x1[imin],D);         /*save best member ever          */
copyPoint(bestit,x1[imin],D);       /*save best member of generation */


while(!(fabs(epsilon)<EPSILON && count>=gen_max))
{
        for(i=0;i<NP;i++)
        {
                do a=(int)(rnd_uni()*NP); while(a==i);
                do b=(int)(rnd_uni()*NP); while(b==i || b==a);
                do c=(int)(rnd_uni()*NP); while(c==i || c==b || c==a);
                do d=(int)(rnd_uni()*NP); while(d==i || d==c || d==b ||d==a);
                do e=(int)(rnd_uni()*NP); while(e==i || e==d || e==c ||e==b ||
                e==a);

                /*--------------- DE/rand/1/bin ---------------------*/
                if(strategy == 1)
                {
                        j       = (int)(rnd_uni()*D);
                        for(k=1;k<=D;k++)
                        {
                                if(rnd_uni()<CR || k==D)
                                        trial[j] = x1[c][j]+F*(x1[a][j]-x1[b][j]);
                                else
                                        trial[j] = x1[i][j];

                                if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                                        trial[j] = x1[i][j];
```

```
                j       = (j+1)%D;
            }
        }
        /*--------------- DE/best/1/bin ---------------------*/
        else if(strategy == 2)
        {
            j       = (int)(rnd_uni()*D);
            for(k=1;k<=D;k++)
            {
                if(rnd_uni()<CR || k==D)
                    trial[j] = bestit[j]+F*(x1[a][j]-x1[b][j]);
                else
                    trial[j] = x1[i][j];
                if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                    trial[j]  = x1[i][j];

                j       = (j+1)%D;
            }
        }
        /*--------------- DE/best/2/bin ---------------------*/
        else if(strategy == 3)
        {
            j       = (int)(rnd_uni()*D);
            for(k=1;k<=D;k++)
            {
                if(rnd_uni()<CR || k==D)
                    trial[j] = bestit[j]+F*(x1[a][j]+x1[b][j]-
                    x1[c][j]-x1[d][j]);
                else
                    trial[j] = x1[i][j];
                if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                    trial[j]  = x1[i][j];
                j       = (j+1)%D;
            }
        }

        /*--------------- DE/rand/2/bin ---------------------*/
        else if(strategy == 4)
        {
            j       = (int)(rnd_uni()*D);
            for(k=1;k<=D;k++)
            {
                if(rnd_uni()<CR || k==D)
                    trial[j] = x1[e][j]+F*(x1[a][j]+x1[b][j]-
                    x1[c][j]-x1[d][j]);
                else
```

```
                trial[j] = x1[i][j];
            if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                trial[j]  = x1[i][j];

            j       = (j+1)%D;
        }
}

/*--------------- DE/rand-to-best/1/bin ---------------------*/
else if(strategy == 5)
{
        copyPoint(trial,x1[i],D);
        j       = (int)(rnd_uni()*D);
        for(k=1;k<=D;k++)
        {
            if(rnd_uni()<CR || k==D)
                trial[j] = trial[j]+F*(bestit[j]-
                trial[j])+F*(x1[a][j]-x1[b][j]);
            else
                trial[j] = x1[i][j];
            if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                trial[j]  = x1[i][j];
            j       = (j+1)%D;
        }
}

/*--------------- DE/rand/1/exp ---------------------*/
else if(strategy == 6)
{
        copyPoint(trial,x1[i],D);
        j       = (int)(rnd_uni()*D);
        k=0;
        do
        {
            trial[j] = x1[c][j]+F*(x1[a][j]-x1[b][j]);
            if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                trial[j]  = x1[i][j];

            j       = (j+1)%D;
            k++;
        }while(rnd_uni()<CR && k<D);

}

/*--------------- DE/best/1/exp ---------------------*/
else if(strategy == 7)
```

```
{
        copyPoint(trial,x1[i],D);
        j       = (int)(rnd_uni()*D);
        k=0;
        do
        {
                trial[j] = bestit[j]+F*(x1[a][j]-x1[b][j]);
                if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                        trial[j]  = x1[i][j];
                j       = (j+1)%D;
                k++;
        }while(rnd_uni()<CR && k<D);

}

/*--------------- DE/best/2/exp ---------------------*/
else if(strategy == 8)
{
        copyPoint(trial,x1[i],D);
        j       = (int)(rnd_uni()*D);
        k=0;
        do
        {
                trial[j] = bestit[j]+F*(x1[a][j]+x1[b][j]-x1[c][j]-
                x1[d][j]);
                if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                        trial[j]  = x1[i][j];
                j       = (j+1)%D;
                k++;
        }while(rnd_uni()<CR && k<D);

}

/*--------------- DE/rand/2/exp ---------------------*/
else if(strategy == 9)
{
        copyPoint(trial,x1[i],D);
        j       = (int)(rnd_uni()*D);
        k=0;
        do
        {
                trial[j] = x1[e][j]+F*(x1[a][j]+x1[b][j]-x1[c][j]-
                x1[d][j]);
                if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                        trial[j]  = x1[i][j];
                j       = (j+1)%D;
```

```
                k++;
            }while(rnd_uni()<CR && k<D);

        }

        /*--------------- DE/rand-to-best/1/exp ---------------------*/
        else if(strategy == 10)
        {
            copyPoint(trial,x1[i],D);
            j       = (int)(rnd_uni()*D);
            k=0;
            do
            {
                trial[j] = trial[j]+F*(bestit[j]-
                trial[j])+F*(x1[a][j]-x1[b][j]);
                if(trial[j]>xhigh[j] || trial[j]<xlow[j])
                    trial[j]  = x1[i][j];
                j       = (j+1)%D;
                k++;
            }while(rnd_uni()<CR && k<D);

        }

        score   = evaluate(trial);
        if(score<=cost[i])
        {
            copyPoint(x2[i],trial,D);
            cost[i]  = score;
        }
        else
            copyPoint(x2[i],x1[i],D);
}

for(i=0;i<NP;i++)
        copyPoint(x1[i],x2[i],D);

imin = 0;
for (i=1; i<NP; i++)
{
if (cost[i]<cmin)
{
        cmin = cost[i];
        imin = i;
}
}
epsilon = evaluate(bestit);
```

```
        copyPoint(bestit,x1[imin],D);       /* save best member of generation */
        epsilon -= evaluate(bestit);        /* Determines the epsilon value */
        count++;

    }
        min_cost        = 0;

        for(i=1;i<NP;i++) if(cost[i] < cost[min_cost]) min_cost       = i;

        copyPoint(Point,x1[min_cost],D);
        result  = evaluate(Point);
        return result;
    }
```

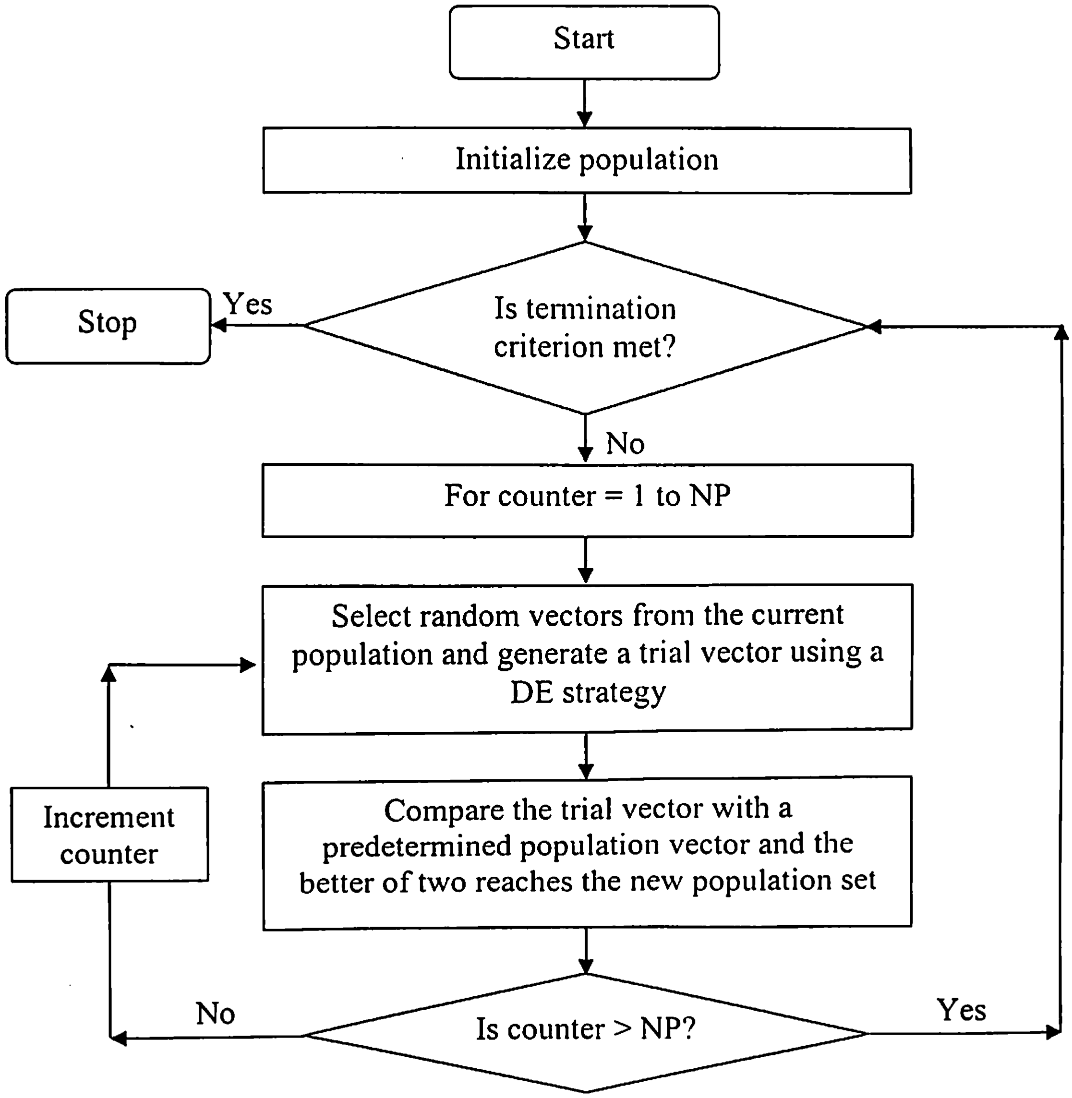

Fig. C-2 Flow chart of computer program for Differential Evolution

C-3 PSEUDO CODE OF SIMULATED ANNEALING AND SIMULATED QUENCHING

```
double sim(double *xmin,double *xmax,int max_itr,double coolingRate,double T)
{
        /* Declarations */
        double *x0, *x1;
        int i, terminate, itr, rejected,tag;
        double T0, min_temp, r,delE, E1, E0;
        struct timeb start,end;

        /* Initialize parameters */
        dimension      = PARAMS;

        /* STEP 1 : Setup the initial point and temperature */
        x0     = (double *)malloc(sizeof(double)*dimension);
        x1     = (double *)malloc(sizeof(double)*dimension);
        for(i=0;i<dimension;i++)
                x0[i]   = 0.5*(xmin[i]+xmax[i]);
        E0     = function(x0);
        T0     = T;
        stage  = 1;
        itr=0;
        terminate      = FALSE;
        min_temp       = MINTEMP;
        do
        {
                rejected        = TRUE;
                do
                {
                        for(i=0;i<dimension;i++)
                                x1[i]   = neighbour(x0[i],xmin[i],xmax[i]);

                        E1      = function(x1);
                        E0      = function(x0);
                        delE    = E1-E0;
                        if(delE < 0)
                        {
                                itr++;
                                rejected        = FALSE;
                                tag = isClose(x0,x1,EPSILON);
                                copyPoint(x0,x1);
                        }
                        else
                        {
                                r= random_float();
```

```
                    if(r<=exp(-delE/T) || T<min_temp)
                    {
                            itr++;
                            rejected        = FALSE;
                            tag = isClose(x0,x1,EPSILON);
                            copyPoint(x0,x1);
                    }
                    else
                    {
                            rejected        = TRUE;
                    }
            }

        }while(rejected);
        if(!(itr%max_itr))
        {
            stage++;
            /* Annealing Schedule in Simulated Annealing*/
            T       = T*coolingRate;

            /* Annealing Schedule in Simulated Quenching*/
            T       = T0/exp((1-coolingRate)*stage);
        }
        else
            if(T<min_temp && tag)
                terminate       = TRUE;

        }while(!terminate);
    E1      = function(x1);
    copyPoint(Point,x1);
    free(x1);
    free(x0);
    finTemp = T;
    return E1;
}
```

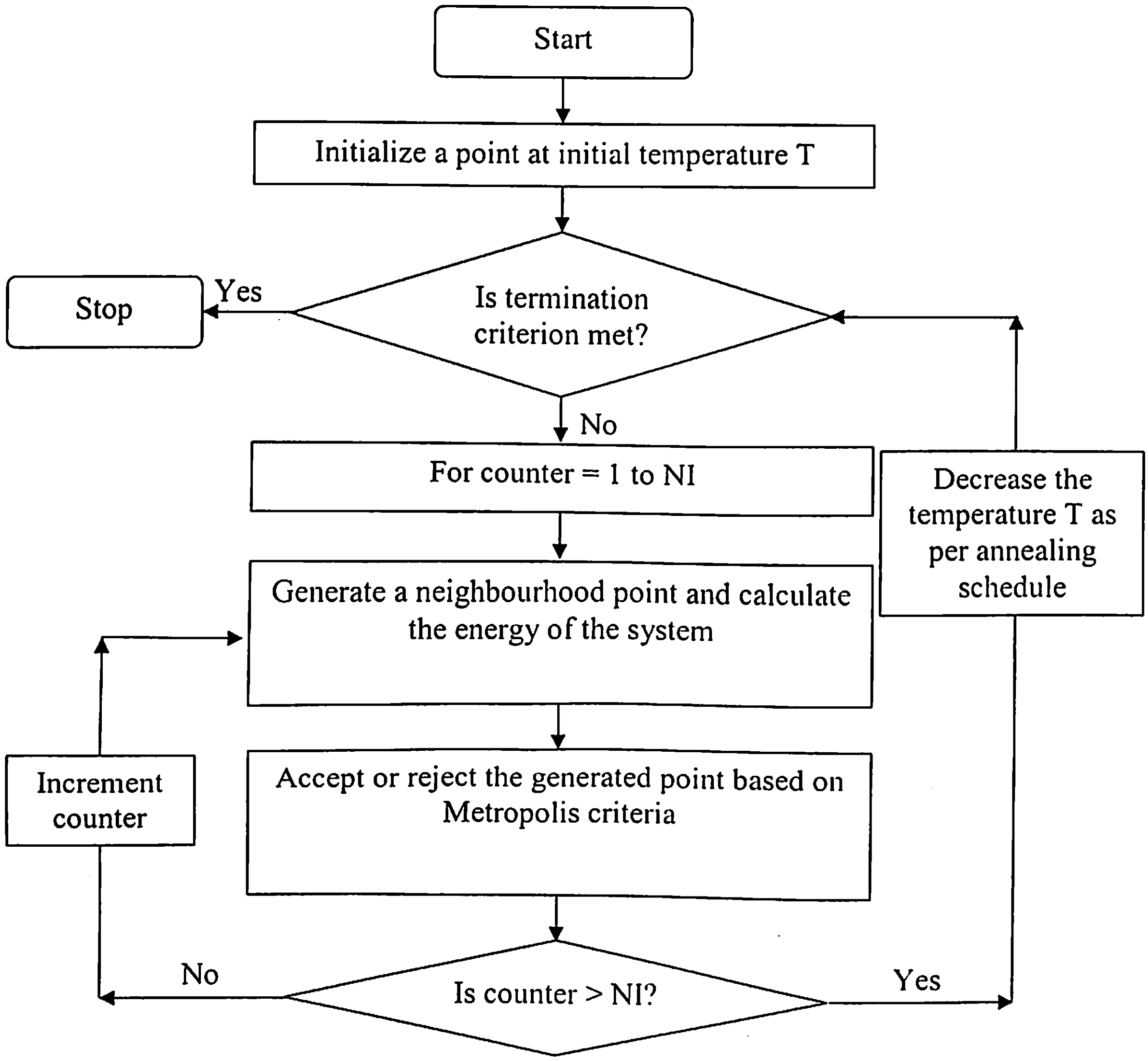

Fig. C-3 Flow chart of computer program for Simulated Annealing and Simulated Quenching

APPENDIX D

Flowchart of the MCDM Techniques

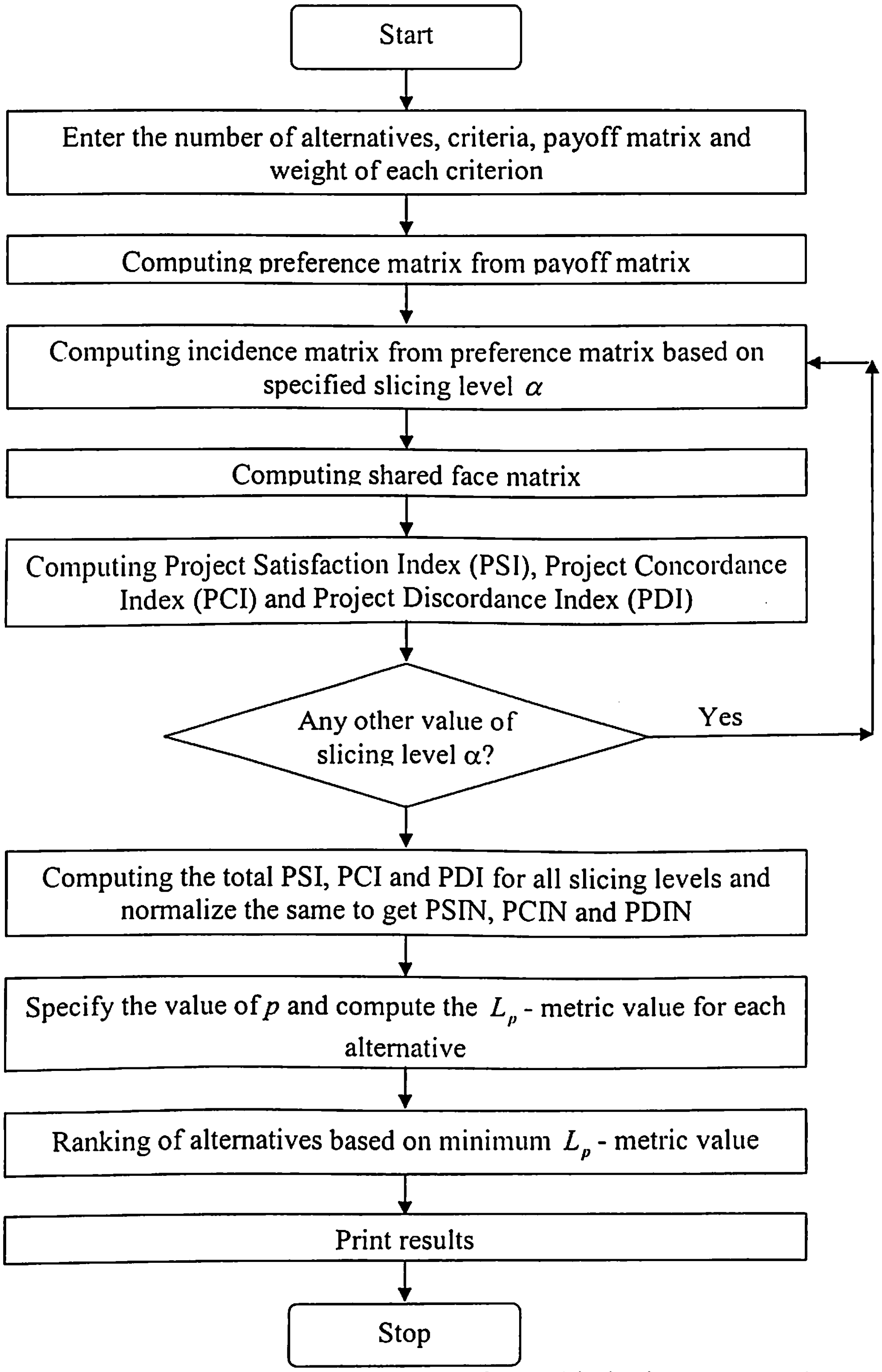

Fig. D-1 Flow chart of computer program for Multicriterion Q-Analysis-2

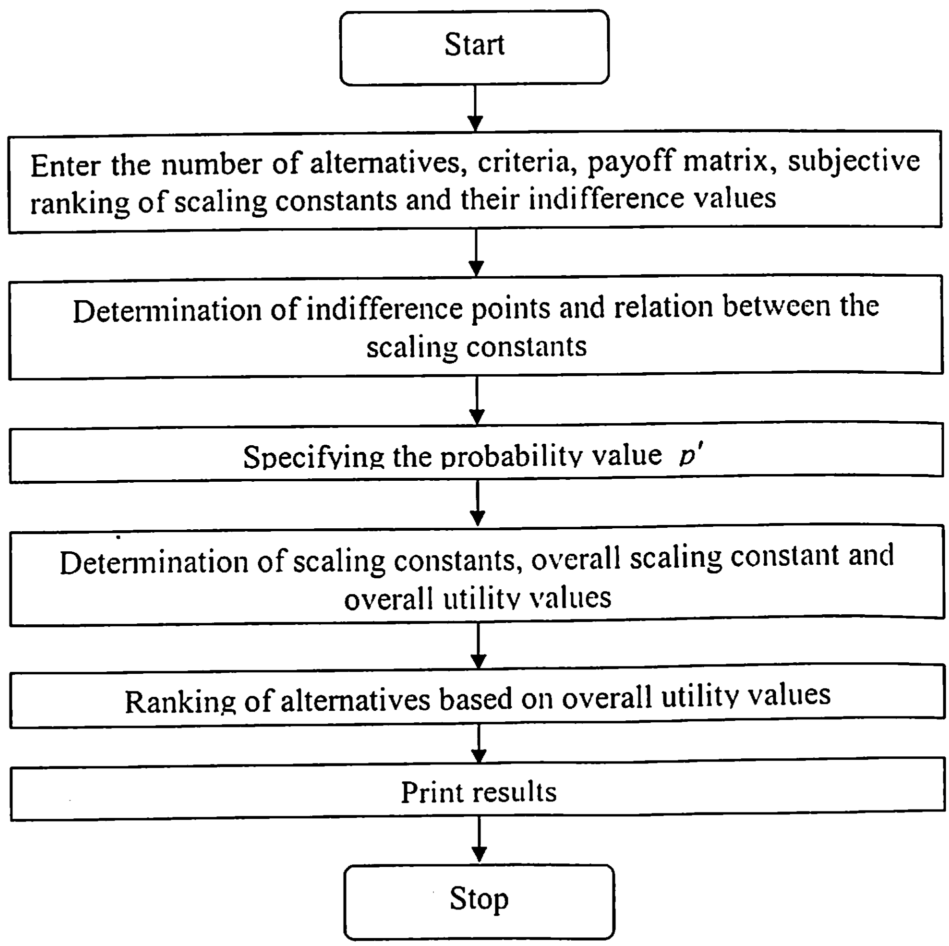

Fig. D-2 Flow chart of computer program for Multi Attribute Utility Theory

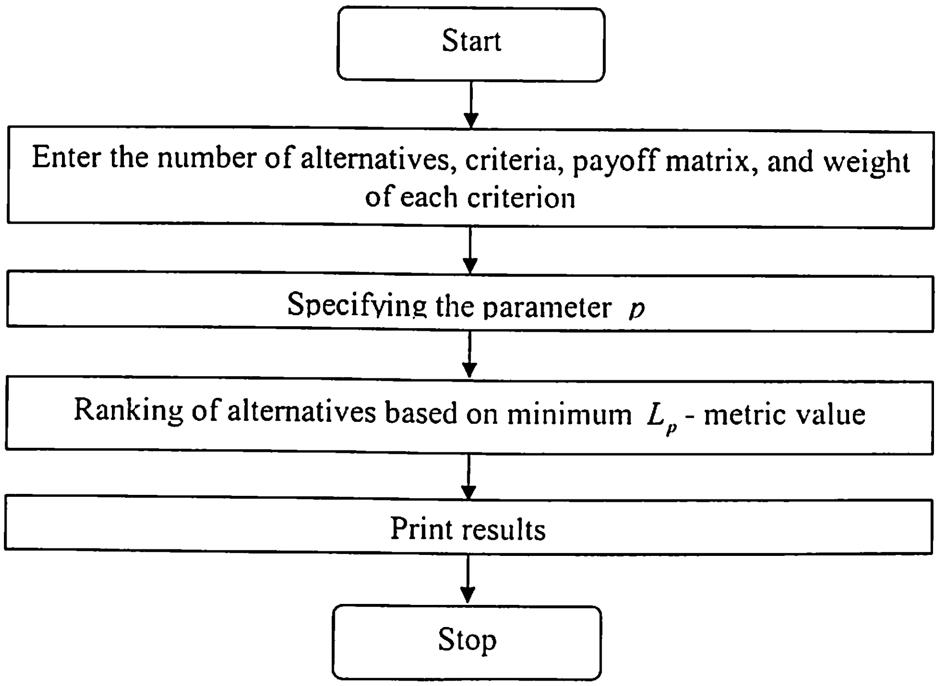

Fig. D-3 Flow chart of computer program for Compromise Programming

APPENDIX E

SAMPLE CALCULATIONS RELATED TO MCDM TECHNIQUES, SPEARMAN RANK COEFFICIENT VALUES

The sample calculations for Multicriterion Q-Analysis-2, Compromise Programming and Spearman Rank Correlation technique are presented below. Sample calculations for Multi Attribute Utility Theory are not presented here as it is explained in detail in Section 6.5.3.

E-1 MULTICRITERION Q-ANALYSIS-2 (MCQA-2)

The procedure for calculating Project Satisfaction Index (PSI), Project Concordance Index (PCI) and Project Discordance Index (PDI) are explained here with reference to Section 4.6.1. The slicing level chosen for this example is $\alpha(1) = 33$. The preference matrix i.e., the payoff matrix in this study (Table 6.37) is transformed into incidence matrix$[T(1)]$ based on the slicing level $\alpha(1)$. If the element in the preference matrix (U') is greater than or equal to the slicing level $\alpha(1)$, the value of the element in the incidence matrix$[T(1)]$ is 1 and if it is less than the slicing level $\alpha(1)$, the element in the incidence matrix$[T(1)]$ is 0. Table E-1 presents the incidence matrix$[T(1)]$ for slicing level of $\alpha(1) = 33$.

Shared face matrix is calculated as $[T(1) \times T(1)^{tr}] - \mathrm{I}$, where *tr* is the transpose operator and I is the matrix of unity and presented in Table E-2. All the necessary information is in the upper triangular portion of the shared face matrix and is called Q-vector. The elements of the shared face matrix represent the connectivity levels. Reading across a row or down a column associated with an element provides a measurement of the connectivity of that element with the other elements. Connectivity is of two types, either the elements of shared face matrix can be independent at a connectivity level or they can be interconnected. An element is independent if the appearance of that element is restricted only to the main diagonal and no other place in the shared face matrix. Similarly, if an element appears anywhere inside the shared face matrix other than the main diagonal then it is said to be interconnected at the intersection of rows and columns.

Table E-1 Incidence matrix for slicing level of $\alpha(1) = 33$

Groups	LDW	TSI	CUW	PF	EI	CPR	EC
G1	0	1	0	1	1	0	1
G2	1	1	1	1	1	1	1
G3	0	1	0	1	1	1	1
G4	1	1	1	1	1	1	1
G5	1	1	1	1	1	1	1
G6	1	1	0	1	1	1	1
G7	1	1	1	1	1	1	1
G8	1	1	1	1	1	1	1

Table E-2 Shared face matrix for slicing level of $\alpha(1) = 33$

Groups	G1	G2	G3	G4	G5	G6	G7	G8
G1	3	3	3	3	3	3	3	3
G2		6	4	6	6	5	6	6
G3			4	4	4	4	4	4
G4				6	6	5	6	6
G5					6	5	6	6
G6						5	5	5
G7							6	6
G8								6

Hence in this case, rows 2, 4, 5, 7 and 8 are interconnected with each other at connectivity level 6. This is represented as [2 4 5 7 8]. It is also possible for a connectivity level to be both independent and interconnected at different rows. It is to be noted that the connectivity of the higher level are carried over to the lower connectivity level. The connection details at the different connectivity levels are as follows:

At connectivity level 6 :

Independent : Empty

Interconnected : [2 4 5 7 8]

At connectivity level 5 :

Independent : Empty

Interconnected : [2 4 5 7 8 6]

At connectivity level 4 :

Independent : Empty

Interconnected : [2 4 5 7 8 6 3]

At connectivity level 3 :

Independent : Empty

Interconnected : [2 4 5 7 8 6 3 1]

At connectivity level 2 :

Independent : Empty

Interconnected : [2 4 5 7 8 6 3 1]

At connectivity level 1 :

Independent : Empty

Interconnected : [2 4 5 7 8 6 3 1]

At connectivity level 0 :

Independent : Empty

Interconnected : [2 4 5 7 8 6 3 1]

Based on these connectivity levels, Δq for different alternatives is calculated based on the q_{max} and q_{min}. q_{max} of an alternative (row) is the value of the connectivity level where it first occurs. q_{min} of an alternative (row) is the value of that connectivity level where it first becomes interconnected. Δq is the difference between q_{max} and q_{min}. MCQA-2 reduces an MCDM problem to a tradeoff between three conflicting indices: PSI, PCI and

PDI for each alternative. Based on the Eq. 4.30, PCI for each alternative is calculated. Table E-3 presents Δq and PCI of each alternative for $\alpha(1) = 33$.

Table E-3 Δq and PCI of each alternative for $\alpha(1) = 33$

Alternative	G1	G2	G3	G4	G5	G6	G7	G8
Δq	0	0	0	0	0	0	0	0
PCI	0	0	0	0	0	0	0	0

PDI is calculated in a similar way as PCI using the complimentary of incidence matrix. The sum of multiplication of each row element in the incidence matrix with the corresponding weights of performance criteria gives V. PSI of the corresponding alternative is determined by multiplying V with the slicing level α (as per Eq. 4.28). Table E-4 presents the PSI and PDI of each alternative for slicing level $\alpha(1) = 33$.

Table E-4 PSI and PDI of each alternative for $\alpha(1) = 33$

Alternative	G1	G2	G3	G4	G5	G6	G7	G8
PSI	21.55	33.00	27.91	33.00	33.00	29.11	33.00	33.00
PDI	33	0	0	0	0	0	0	0

E-2 COMPROMISE PROGRAMMING (CP)

Table E-5 shows the values of each criterion for group G1 and the maximum value for each criterion.

Table E-5 Payoff matrix after classification

Groups	LDW	TSI	CUW	PF	EI	CPR	EC
G1	27	63	31	57	51	27	48
MAX/BEST	49	82	56	78	64	64	77

The L_p - metric value for group G1 is determined using the Eq. 4.36 (a) for p=1 (Section 4.6.3) and as follows:

$$L_p(G1) = \left[\sum_{j=1}^{J} w_j^p \left|f_j^* - f(a)\right|^p\right]^{\frac{1}{p}}$$

$$= \begin{bmatrix} 0.0362^1 \times |49-27|^1 + 0.0881^1 \times |82-63|^1 + 0.1179^1 \times |56-31|^1 + 0.1171^1 \times |78-57|^1 \\ + 0.3554^1 \times |64-51|^1 + 0.1928^1 \times |64-27|^1 + 0.0925^1 \times |77-48|^1 \end{bmatrix}^{1/1}$$

$$= 22.3132$$

Similarly, the L_p - metric value for other groups is also determined.

E-3 SPEARMAN RANK CORRELATION COEFFICIENT (R)

Suppose two MCDM techniques, namely, MCQA-2 (p=1) and MAUT are used to rank the given eight alternatives as given in columns U and V of Table E-6. D_a is the difference in ranks and A' is the number of alternatives (eight in this case).

Table E-6 Spearman rank correlation coefficient

Groups	Ranking by MCQA-2 (p=1)	Ranking by MAUT	D_a=U-V	D_a^2
	U	V		
G1	6	8	-2	4
G2	7	6	1	1
G3	2	4	-2	4
G4	4	3	1	1
G5	3	1	2	4
G6	8	7	1	1
G7	1	2	-1	1
G8	5	5	0	0
			$\sum D_a^2$	16

Then Spearman Rank Correlation Coefficient R between MCQA-2 (p=1) and MAUT is calculated as shown below and found to be 0.8095.

$$R = 1 - \frac{6\sum_{a=1}^{A'} D_a^2}{A'(A'^2 - 1)} = 1 - \frac{6 \times 16}{8(8^2 - 1)} = 0.8095$$

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RESUME

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