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Multiobjective Fuzzy and Deterministic Goal Programming for Optimal Irrigation Planning

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ABSTRACT: Multiobjective Deterministic Goal Programming (MDGP) and Multiobjective Fuzzy Goal Programming (MFGP) methods are applied to obtain optimal irrigation planning for Jayakwadi irrigation project, India. Three objectives viz., net benefits, agricultural production and labour employment are considered for the planning problem. Upper and lower bounds for the objectives are obtained by solving the three objective functions individually. These are used as the limits for fixing the aspiration levels in MDGP and MFGP models. In both cases, six strategies (S1 to S6) with different priorities of labour employment, net benefits and agricultural production are formulated and analysis is carried out. It is observed from the analysis of MDGP that one goal is satisfied when net benefits are given the highest priority and two goals are satisfied when labour employment and agricultural production are accorded highest priority. In case of MFGP, one goal is satisfied when labour employment is given highest priority and one goal is satisfied when agricultural production is given highest priority. None of the goals are satisfied when net benefits are given highest priority. It is concluded that MFGP and MDGP are potential methods that can be extended to other planning scenarios in a conflicting environment.

INTRODUCTION

Increasing demand for water resources for municipal (drinking water etc.) and industrial sectors, and for growing population with changing life styles reduce the available water for irrigation. This complexity is further enhanced with the uncertainty in the resources availability including inflows and conflicting nature of irrigation planning objectives in multiobjective framework. This necessitates formulation of a suitable irrigation planning strategy for effective management.

In the present study, Multiobjective Deterministic Goal Programming (MDGP) and Multiobjective Fuzzy Goal Programming (MFGP) methods are applied for optimal irrigation planning of Jayakwadi irrigation project, India.

LITERATURE REVIEW

A brief literature review is presented in this paper on deterministic and Fuzzy Goal Programming applications for irrigation planning. Nayak and Panda (2001) applied Sequential Linear Fuzzy Programming and Goal Programming for the case study of Mahanadi delta of India and analyzed five objectives, namely, benefit maximization, production maximization, investment minimization, labour maximization and labour minimization. Biswas and Pal (2005) applied Fuzzy Goal Programming for solving land use planning problems in agricultural systems for optimal production of several seasonal crops in a planning year. The methodology is applied to a study region in Nadia district, West Bengal, India. Tsakiris and Spiliotis (2006) applied Fuzzy Goal Programming to the case study of Thessaly Plain in Greece for analyzing cropping pattern planning with water supply from surface and groundwater. Similar studies are reported by Chen and Tsai (2001) and Foued and Sameh (2001).

DESCRIPTION OF GOAL PROGRAMMING

Goal Programming (GP) method involves formulation of specific goals/targets corresponding to the objective

[1]Conference speaker

functions/criteria in a prioritized order. A satisfactory solution is the one that minimizes the deviations from the set of goals. It can be expressed as (Ignizio, 1976; Tamiz *et al.*, 1998; Nayak and Panda, 2001),

$$\text{Min } PL_1(d_1^-, d_1^+), PL_2(d_2^-, d_2^+), \ldots, PL_r(d_r^-, d_r^+) \quad \ldots (1)$$

subject to

$$Z_j(X) - d_j^+ + d_j^- = Z_j^* \text{ for } j = 1, 2, 3, \ldots, n \quad \ldots (2)$$

$$g_i(X) - d_i^+ + d_i^- = b_i^* \text{ for } i = 1, 2, \ldots, m \quad \ldots (3)$$

and other constraints and bounds.

where $PL_r(\ ) = r^{th}$ priority level or hierarchical priority assigned to different objectives/criteria; $Z_j(X) =$ objective function j; $g_i(X) =$ constraint i; d_j^-, $d_i^- =$ under achievement of the objective j and constraint i; d_j^+, $d_i^+ =$ over achievement of the objective j and constraint i; Z_j^*, b_i^* = targets for objective j and constraint i. This method is adopted for optimization sequentially until a stage is reached where subsequent satisfaction of a goal affects the previously satisfied goals (Ignizio, 1976). Goal Programming can also be extended to the fuzzy environment with simple modifications (Zimmermann, 1996). Equations 2 and 3 can be reorganized as follows,

$$\left[\mu(Z_j(X))\right] - d_j^+ + d_j^- = \lambda_j \quad \ldots (4)$$

$$\left[\mu(g_i(X))\right] - d_i^+ + d_i^- = \lambda_i \quad \ldots (5)$$

where $\mu(Z_j(X))$, $\mu(g_i(X))$ are membership functions for objective functions and constraints and λ_j, λ_i are targets for membership values for objective(s) and constraint(s). λ_j, λ_i values can be varied between 0 to 1. Linear membership functions for maximization scenario for objectives are the following,

$$\mu(Z_j(X)) = 0 \text{ for } Z_j(X) \le Z_L$$

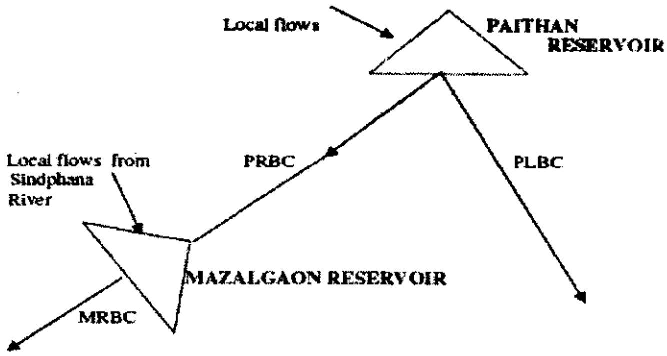
$$\mu(Z_j(X)) = \left[\frac{Z - Z_L}{Z_U - Z_L}\right] \text{ for } Z_L \le Z_j(X) \le Z_U \quad \ldots (6)$$

$$\mu(Z_j(X)) = 1 \text{ for } Z_j(X) \ge Z_U$$

Here Z_L and Z_U are lower and upper bounds. Other notations are analogous/similar to those for Goal Programming. More details of Goal Programming and Fuzzy Goal Programming are available in Tamiz *et al.* (1998), Biswas and Pal (2005).

CASE STUDY

The Jayakwadi irrigation project is a major irrigation project consisting of a two reservoir systems, namely, Paithan and Mazalgaon, located on the Godavari River. The project is mainly intended for irrigation (Jayakwadi Revised Project Report, 1985). Two canal systems are originating from Paithan reservoir, namely Paithan Left Bank Canal (PLBC) and Paithan Right Bank Canal (PRBC) having culturable command areas of 1,42,000 ha and 42,000 ha respectively. After some distance downstream alongPRBC, Mazalgaon reservoir was formed with the additional source of supply from Sindphana river, a tributary of Godavari river. There is 93885 ha command area under Mazalgaon reservoir and the canal system is termed as Mazalgaon right bank canal (MRBC). More details about the project are available in the Jayakwadi Revised Project Report (1985). Figure 1 presents schematic diagram of the case study area.



PLBC = Paithan Left Bank Canal
PRBC = Paithan Right Bank Canal
MRBC = Mazalgaon Right Bank Canal

Fig. 1: Schematic diagram of the case study

MATHEMATICAL MODELING

The three planning objectives considered are maximization of net benefits, maximization of agricultural production and maximization of labour employment. Mathematical modeling of the three conflicting objectives is as follows (Raju *et al.*, 2006):

Objective 1: The net benefits (*BM*) under different crops from command areas of PLBC, PRBC and MRBC are to be maximized. These are obtained by subtracting the cost of surface water from gross benefits of crops. Mathematically it can be expressed as,

$$BM = \sum_{i=1}^{10} BL_i AL_i + \sum_{i=1}^{10} BR_i AR_i + \sum_{i=1}^{10} BM_i AM_i - C_w \sum_{t=1}^{12} (RLR_t + RM_t) \quad \ldots (7)$$

where i = Crop index [1 = Sugar-cane (SC, P), 2 = Banana (BA, P), 3 = Chillies (CH, TS), 4 = Cotton (CT, TS), 5 = Sorghum (SO, S), 6 = Paddy (PA, S), 7 = Sorghum (SO, W), 8 = Wheat (WH, W), 9 = Gram (GR, W), 10 = Groundnut (GN, HW)]; (First abbreviation in parenthesis represents crop and second for season); S = Summer, W = Winter, TS = Two season, HW = Hot weather, P = Perennial, t = Time index (1 = January, ..., 12 = December). BM = Net benefits from the whole planning region (Indian Rupees); BL_i, BR_i, BM_i = Gross benefits from the crops (excluding costs of fertilizers, labour employment, etc.) from the command areas of PLBC, PRBC, MRBC, respectively (Indian Rupees); AL_i, AR_i, AM_i = Area of crop i grown in the command areas of PLBC, PRBC, MRBC (ha); C_w = Cost of surface water (Rs/Mm^3); RLR_t = Total water releases from Paithan reservoir to command areas of PLBC and PRBC (Mm^3); RM_t = Water releases from Mazalgaon reservoir to command area of MRBC (Mm^3).

Objective 2: Agricultural production (PM) of all the crops for the whole planning region is to be maximized,

$$PM = \sum_{i=1}^{10} Y_i (AL_i + AR_i + AM_i) \quad \ldots (8)$$

Where PM = Agricultural production (Tons); Y_i = Yield of the crops (Tons/ha).

Objective 3: Labour employment for each crop i for the whole year for the whole planning region is to be maximized,

$$LM = \sum_{t=1}^{12} \sum_{i=1}^{10} L_{it} (AL_i + AR_i + AM_i) \quad \ldots (9)$$

Where LM = Labour requirement for whole planning horizon (Man-Days); L_{it} = Labour requirement for crop i in month t (Man-Days).

The above three objectives are subjected to the constraints based on continuity equation, crop area restrictions, crop water diversions, canal capacity restrictions, live storage restrictions and crop diversification considerations. Similar constraints are formulated for Mazalgaon reservoir system.

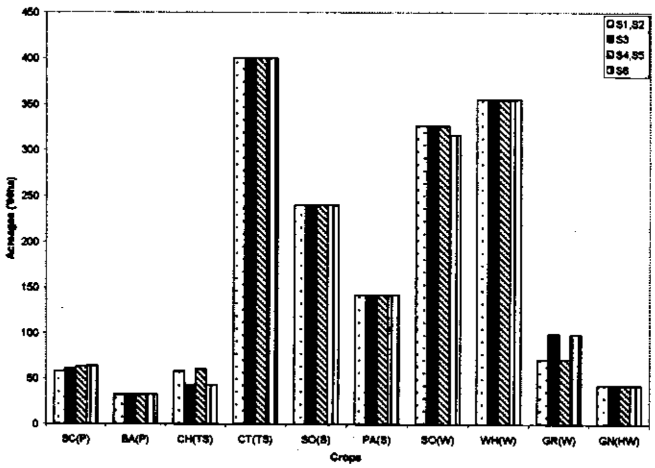
RESULTS AND DISCUSSION

In the present study three objectives are considered as goals for Goal Programming analysis. Initially the model is solved individually to obtain the upper and lower bounds for each objective function. These are used as the limits to fix the goals/targets. Lower, upper, target for labour employment (10^7 Man days) are 3.1623, 3.6782, 3.5000. For agricultural production (10^6 tons), these are 1.7017, 2.2287, 2.2000 whereas for net benefits (10^9 Rs.), these are 1.7550, 2.1120, 2.1000 respectively. In total, six strategies (S1 to S6) with different priority levels of labour employment, net benefits and agricultural production are formulated viz., **(S1):** minimise under achievement for LM (goal 1, G1), BM (goal 2, G2), PM (goal 3, G3); **(S2):** minimise under achievement for LM (G1), PM (G2), BM (G3); **(S3):** minimise under achievement for BM (G1), LM (G2), PM (G3); **(S4):** minimise under achievement for PM (G1), LM (G2), BM (G3); **(S5):** minimise under achievement for PM (G1), BM (G2), LM (G3); **(S6):** minimise under achievement for BM (G1), PM (G2), LM (G3). Analysis is carried out using Multiobjective Deterministic Goal Programming (MDGP) and Multiobjective Fuzzy Goal Programming (MFGP) methods.

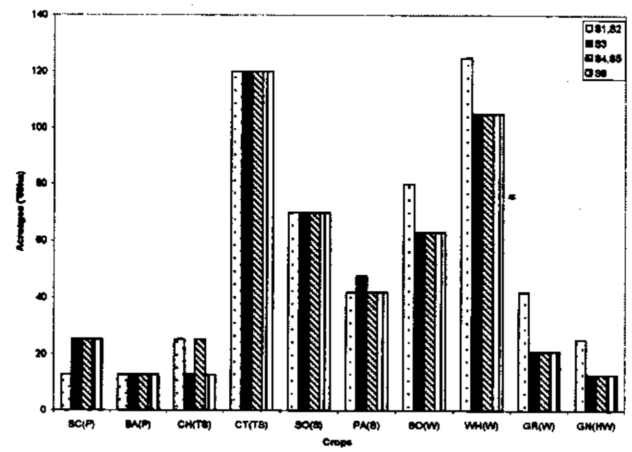
Multiobjective Deterministic Goal Programming

Multiobjective Deterministic Goal Programming (MDGP) is applied to the case study and program is run for chosen six strategies. Figures 2(a), 2(b) and 2(c) present cropping pattern for PLBC, PRBC and MRBC which is self explanatory. It is observed that the resulting pattern (i.e., cropping pattern, storage and release policies) of strategies S1 and S2 (labour employment is given highest priority i.e., goal 1) is same. Similarly the resulting pattern for strategies S4 and S5 (agricultural production is given highest priority i.e., goal 1) is same. However, the resulting pattern for S3, S6 are different (even though net benefits are given highest priority i.e., goal 1). The following inferences are drawn from MDGP analysis:

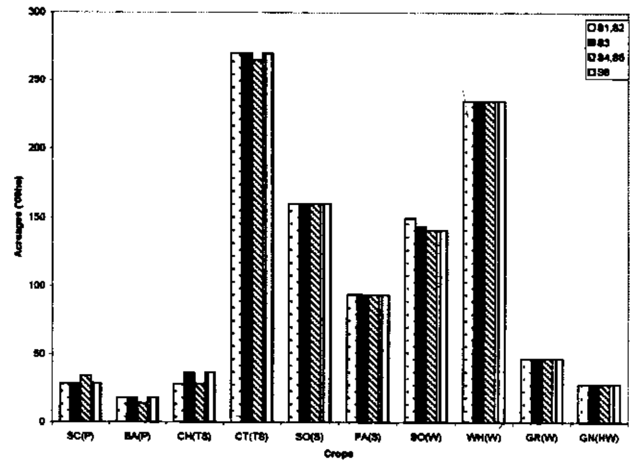
- Cropping pattern obtained for PLBC is shown in Figure 2(a) which indicates similar values for Cotton (TS), Sorghum (S), Paddy (S), Wheat(W) and Groundnut(HW) for all strategies. It is different for Sugarcane(P) for different strategies whereas for Sorghum (W), these are same for strategies S1 to S5 and different for S6. Similar trend is observed for Banana (P) where acreages are same for strategies S3 to S6.
- Cropping pattern obtained for PRBC is shown in Figure 2(b) which indicates similar values for Banana (P), Cotton (TS), Sorghum (S) for all strategies. Cropping pattern is same for Sugarcane (P), Sorghum (W), Wheat (W), Gram (W), Groundnut (HW) for S3 to S6.



(a)



(b)



(c)

Fig. 2(a), (b), (c): Cropping pattern for PLBC, PRBC, MRBC for MDGP

- Figure 2(c) shows the cropping pattern obtained for MRBC wherein the values are same for Sorghum (S), Paddy (S), Wheat (W), Gram (W) and Groundnut (HW) for all the six strategies.
- The monthly storage policy of Paithan reservoir obtained indicates similar values for strategies S1 and S2. They are similar for strategies S4 and S5. However, they are different for S3 and S6. Similar inferences can be drawn for Mazalgaon reservoir.
- The results obtained for Labour Employment LM (10^7 Man days), Agricultural Production PM (10^6 tons), Net Benefits BM (10^9 Rs.) for S1 and S2 are 3.5000, 1.9993, 2.1000. These are 3.5000, 2.1999, 2.0643 for S4 and S5 and are 3.4462, 2.1391, 2.0999 for S3 and 3.4311, 2.1698, 2.1000 for S6.
- Table 1 presents brief summary of different strategies in terms of under achievement values for the chosen targets. There is no over achievement. In case of strategies S1, S2 labour employment and net benefits achieved their targets (no under achievement/over achievement) but in case of agricultural production there is under achievement of 0.2006×10^6 tons. In case of strategy S3, both labour employment and agricultural production could not achieve their targets whereas net benefits are able to achieve their targets exactly. Similar inferences can be drawn for other strategies as seen from Table 1.

Multiobjective Fuzzy Goal Programming

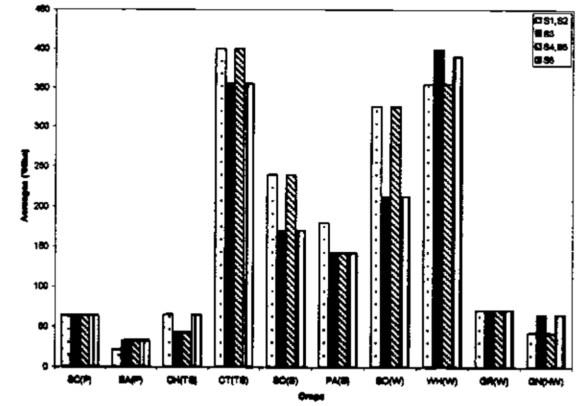
Multiobjective Fuzzy Goal Programming (MFGP) is formulated by assuming linear membership function (equation 6) and only objectives are considered as fuzzy. All the existing constraints and bounds in the model are assumed as crisp. Membership goals/targets λ are assumed as unity (maximum membership value). Under and over achievement variables are added to each of the membership functions (equation 4). Six strategies are formulated as those of MDGP.

Inferences emanated from MFGP analysis are:

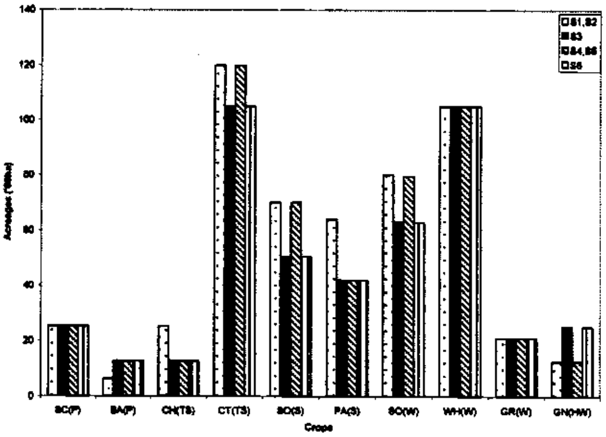
- Cropping pattern obtained for PLBC (Figure 3(a)) indicates similar values for Gram (W) for all strategies. Values for Sugarcane(P), Banana (P), Chillies (TS), Paddy (S) are same for strategies 3, 4 and 5.
- Cropping pattern obtained for PRBC (Figure 3(b)) indicates similar values for Sugarcane (P), Wheat (W), Gram (W) for all strategies. Sugarcane (P), Banana (P), Values for Chillies (TS), Paddy (S) are same for strategies 3, 4 and 5.
- Cropping pattern obtained for MRBC (Figure 3(c)) indicates similar values for all strategies for Cotton (TS), Wheat (W), Gram (W) and Groundnut (HW) for all strategies. Values for Chillies (TS), Paddy (S), Sorghum (W) are same for strategies 3, 4 and 5.

Table 1: Summary of Strategies for MDGP in Terms of under Achievement

Strategy Goal	*S1*	*S2*	*S3*
G1	0.00 (Man days)	0.00 (Man days)	0.00 (Rs.)
G2	0.00 (Rs.)	0.2006×10^6 (tons)	0.0537×10^7 (Man days)
G3	0.2006×10^6 (tons)	0.00 (Rs.)	0.0608×10^6 (tons)
Strategy Goal	S4	S5	S6
G1	0.00 (tons)	0.00 (tons)	0.00 (Rs.)
G2	0.00 (Man days)	0.0356×10^9 (Rs.)	0.03012×10^6 (tons)
G3	0.0356×10^9 (Rs.)	0.00 (Man days)	0.0688×10^7 (Man days)



(a)



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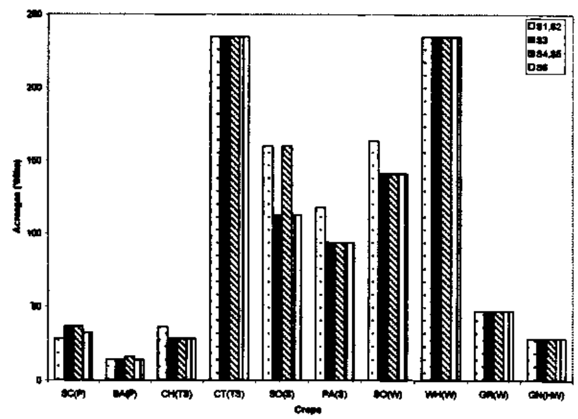

(c)

Fig. 3(a), (b), (c): Cropping pattern for PLBC, PRBC, MRBC for MFGP

- The monthly storage policy of Paithan reservoir indicates similar values for strategies S1 and S2. These are same for strategies S4 and S5. However, they are different for S3 and S6. Similar inferences can be drawn for Mazalgaon reservoir.
- The results obtained for Labour Employment LM (10^7 Man days), Agricultural Production PM (10^6 tons), Net Benefits BM (10^9 Rs.) for S1 and S2 are 3.6782, 2.0692, 1.8872. These are 3.4284, 2.2287, 2.0540 for S4 and S5 and are 3.1991, 2.1568, 1.9268 for S3 and 3.2401, 2.1168, 1.9274 for S6, respectively.
- Table 2 presents brief summary of different strategies with reference to under achievement values with reference to their targets (in this case it is 1). In case of strategies S1, S2, labour employment achieved their targets (no under achievement/over achievement) but in case of agricultural production there is under achievement of 0.303 and in case of net benefits it is 0.63. In case of strategies S4, S5, agricultural production achieved their target (no under achievement/over achievement) but in case of labour employment there is under achievement of 0.484 and in case of net benefits it is 0.163. In case of strategies S3 and S6, labour employment, agricultural production, net benefits could not reach their target of 1.

Comparative Analysis of MDGP and MFGP

- It is observed from the analysis of MDGP (Table 1) that only one goal is satisfied when net benefits are given the highest priority (strategies S3, S6) and two goals are satisfied when labour employment (S1, S2) and agricultural production (S4, S5) are accorded highest priority.
- It is also inferred from Table 2 that one goal is satisfied when labour employment is given highest priority (S1, S2) and agricultural production is given highest priority (S4, S5). None of the goals are satisfied when net benefits (S3, S6) are given highest priority.

Table 2: Summary of Strategies for MFGP in Terms of under Achievement

Strategy Goal	S1	S2	S3	S4	S5	S6
G1	0.000	0.000	0.518	0.000	0.000	0.517
G2	0.630	0.303	0.928	0.484	0.163	0.212
G3	0.303	0.630	0.137	0.163	0.484	0.850

High under achievement values in both MDGP and MFGP are due to the high values of chosen targets. This problem may be mitigated by choosing lower targets in which case there may be chances of less under achievement values.

This study is of practical significance for fixing realistic goals and giving priority to the goals in the form of strategies. This will help the stakeholders including farmers, officials and social scientists in analyzing the problem in a multifaceted and multiobjective framework. Consequently this will help farmers plan for other inputs such as seeds, fertilizers and man power accordingly.

The present study can be extended by considering inflow as fuzzy, introducing various levels of targets and different shapes of membership functions. Efforts are already in progress to collect more data and analyze the problem with more dependable inflow levels, which may improve the inferences. However, the methodology proposed remains same, which is the main objective of the present study.

CONCLUSIONS

In the present study Multiobjective Deterministic Goal Programming and Multiobjective Fuzzy Goal Programming methods are applied for optimal irrigation planning. In both cases, six strategies with different priorities of labour employment, net benefits and agricultural production are formulated and analysis is carried out. Fuzziness in the objectives is incorporated in Goal Programming. The following inferences are drawn from the study:

- It is observed from the analysis of MDGP that one goal is satisfied when net benefits are given the highest priority and two goals are satisfied when labour employment and agricultural production are accorded highest priority.
- It is observed that one goal is satisfied when labour employment is given highest priority and one goal is satisfied when agricultural production is given highest priority. None of the goals are satisfied when net benefits are given highest priority.
- It is concluded that MFGP and MDGP are potential methodologies that can be extended to other planning scenarios in a conflicting environment.

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