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Solution of Constrained Economic Emission Dispatch Problem Using Multi-Objective Particle Swarm Optimisation

Sarat Kumar Mishra* and Sudhansu Kumar Mishra**

Abstract : In this paper, the solution of economic load dispatch problem is performed considering it as a multi-objective problem, with operating fuel cost and the environmental emission as two objectives. Here, power balance criterion and generator limits are considered as the two constraints for addressing the economic emission dispatch (EED) problem. An excellent multi-objective optimisation algorithm, namely the multi-objective particle swarm optimisation (MOPSO) has been proposed and employed to solve the EED problem. To avoid the non-convergence due to constraints, a recursive distributed constraint handling technique is used. It has been applied to two test cases and its performance is compared with two other competitive multi-objective evolutionary algorithms (MOEAs). The efficiency of the algorithms were tested in terms of the Pareto front and computational time. It is observed that the MOPSO algorithm is capable of retaining good Pareto solutions by preserving sufficient diversity. It gives a wide option to make a trade-off between fuel cost and emission for two different challenging constraints.

Keywords : Economic load dispatch, multi-objective optimisation, evolutionary computing

1. INTRODUCTION

An electric power system is designed to operate and meet the continuous variation of load power demand. Economic Load Dispatch (ELD) is a program to schedule the output of the committed units of the power system under the varying load demand for most economic condition. Over the years the complexity in the design of the ELD program has gone up due to increasing effect of emissions from fossil fuel based power plants on the environment. The emission and cost of fuel for each unit depend on the amount of power generated. Both of these are nonlinear functions of power output. Minimum cost does not ensure minimum emission and vice versa. The schedule of generation obtained from the ELD must satisfy the power balance condition and the generating limits of the committed units. In other words, the primary objective of ELD is to suitably allocate the power generations from different units at the lowest possible running cost, while satisfying all the system constraints. Thus, it is formed as a multi-objective optimisation problem with nonlinear constraints.

In early days [1], [2] the emission aspects were not considered for solution of the ELD problem. Solution was done using the derivative based Gauss-Siedel or Newton-Raphson algorithms combined with the Lagrangian multiplier method. It was good in solving the cost minimisation as a single-objective problem. These conventional methods are associated with the problem of local minima and often fail in presence of system discontinuities like prohibited zones etc. Chang [3] converted the multi-objective problem to a single-objective one by assigning weights to the operating cost and emission. The weighted sum approach requires many runs of the same algorithm to find the Pareto optimal front. The solutions

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* Asst. Professor, Dept. of EEE, Padmanava College of Engineering, Rourkela-769002, Odisha, India *E-Mail: mishra.sarat@gmail.com*

** Asst. Professor, Dept. of EEE, Birla Institute of Technology, Mesra-835215, Ranchi, Jharkhand, India

arrived by this method do not ensure a uniform Pareto front. The trade-off information is lost when the function is concave. The situation was slightly improved when evolutionary algorithms were used in place of the conventional ones in [5]-[6].

Deb [7]-[8] proposed the non-dominated sorting genetic algorithm which used rank and crowding distance as parameters to arrive at a compromise between the two conflicting objectives. This algorithm gives the Pareto optimal front after one run only. But, this population based genetic algorithm depends upon the biologically inspired factors like mutation and crossover parameters. It needs further improvement in terms of exploring wider area in the search space. Brar et al. made improvements in the search space by adding fuzzy inference system [9]. Panigrahi et al. implemented another evolutionary algorithm, the artificial bee colony optimisation and improved the convergence rate and reliability by considering the prohibited zones and ramp rate limits [10], [14]. Mori et al. made an excellent improvement in the exploration of search space through implementation of particle swarm optimisation for this multimodal problem [13]. He also used adaptive parameter adjustment to improve the results. A significant improvement in search space exploration was attained by Hadji [18]. They incorporated a time varying acceleration of the particles to improve the robustness of the algorithm. Recently, a new algorithm named as differential evolution came up which generates the next set of population of new particles by addition of a differential vector obtained from the difference of the position vectors of two different particles other than the particle undergoing evolution [23]. This algorithm is less dependent on the bio-inspired parameters and avoids premature convergence. Di [17] introduced a marginal analysis correction operator to improve the constraint handling.

2. ECONOMIC EMISSION DISPATCH PROBLEM

The purpose of economic load dispatch problem is to schedule the generation of committed units so as to minimise the operating cost of a power system while supplying the load demand along with transmission losses. The schedule of generation thus arrived for the various generating units in the system must satisfy their minimum and maximum limits. The total cost of fuel required varies with the efficiency of the units, their fuel cost constants and transmission losses incurred.

The cost of fuel for the generator i real power of P_{Gi} is given by

$$F_i = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \tag{1}$$

where, a_i, b_i and c_i are constants for that generator.

The emission from generator i is expressed as

$$E_i = a_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 \tag{2}$$

where, α_i, β_i, γ_i are constants for the generator.

The objective of the ELD problem is to minimise the total fuel cost

$$FT = \sum_{i=1}^{N} F_i \tag{3}$$

Subject to the constraints.

The generated power must be sufficient to supply the demand along with the losses

$$\sum_{i=1}^{N} P_{Gi} = P_D + P_L \tag{4}$$

where, P_D is the load demand and P_L is the transmission loss expressed by Kron's formula

$$PL = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{Gi} B_{ij} P_{Gj} + \sum_{i=1}^{N} B_{10} P_{Gi} + B_{00} \tag{5}$$

B_{ij}, B_{i0} and B_{00} are constants depending on the parameters of the transmission lines of the system. The real power generated should be within the maximum and minimum limits.

$$P_{Gi(min))} \le P_{Gi} \le P_{Gi(max)} \quad i = 1, 2, \ldots, N \tag{6}$$

There is a necessity to modify ELD problem to take care of the environmental emission from the power plant within the limits. Thus the Economic Emission Dispatch (EED) problem has two functions as objectives to be minimised. These two objectives are conflicting in nature, hence a compromise is required between them. There are many solutions to such problems and they are represented on a Pareto optimal front.

The problem can be mathematically written as:

$$\text{Minimise}_{PG}\ [F_T(P_G), E_T(P_G)] \tag{7}$$

Subject to :

$$g(P_G) = 0$$
$$h(P_G) \leq 0$$

where, the equality and inequality constraints are given by equation (8) and (9) respectively.

$$\sum_{i=1}^{N} P_{Gi} - P_D - P_L = 0 \tag{8}$$

$$P_{Gi} - P_{Gi}^{\max} \leq P_{Gi}^{\min} - P_{Gi} \leq 0 \tag{9}$$

3. MULTI-OBJECTIVE PARTICLE SWARM OPTIMISATION ALGORITHM

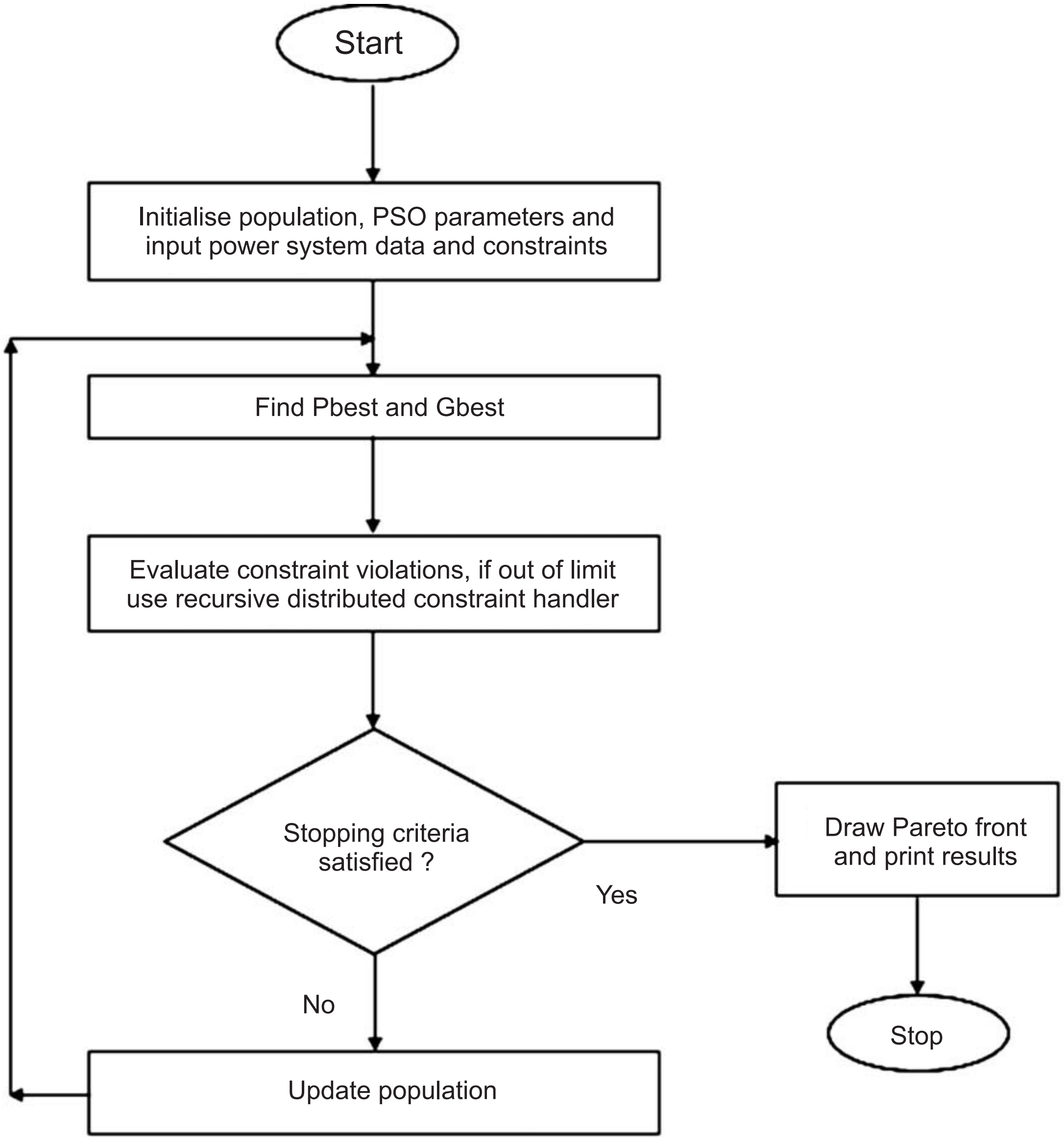

Figure 1: Flow chart of MOPSO

Kennedy and Eberhart proposed that any optimisation problem can be solved by mimicking the movement of a flock of birds and school of fish [4]. The social behaviour of the swarm has two components: they try to change their position and velocity to maximise their chance of getting food and follow the best successful neighbour. This behaviour of swarm was followed to formulate the particle swarm optimisation (PSO) algorithm. In this method of optimisation a local best and a global best solution are identified. The i^{th} particle of the population having the best position (pbest) may be represented by p_i, that gives the best fitness value.

where, $$p_i = (p_{i1}, p_{i2}, \ldots, p_{iN}) \tag{10}$$

The old and new velocity of the particles will be shown in equation (11) and (12) respectively.

$$V_i = (v_{i1}, v_{i2}, \ldots, v_{iN}) \tag{11}$$

$$v_{id}(t) = wv_{id}(t-1) + c_1 r_1 (p_{id} - x_{id})(t-1) + c_2 r_2 (p_{id} - x_{id})(t-1) \tag{12}$$

and the new position of the particle will be

$$x_{id}(t) = x_{id}(t-1) + \chi v_{id}(t) \tag{13}$$

where, $d = 1, 2, \ldots$, D is the dimension of the decision variables and $i = 1, 2, \ldots$, N. χ is the constriction factor which constricts and controls the velocity magnitude. w, c_1 and c_2 are weight parameters and r_1, r_2 are random numbers known as acceleration constants in the range [0, 1].

The flow chart of implementation of MOPSO to our EED problem is shown in fig.1

4. SIMULATION STUDY AND RESULTS

The EED problem was solved for two different standard test cases *i.e.* IEEE 14 bus and IEEE 30 bus. The system data of these two test cases were obtained from the website www.ee.washington.edu/research/pstca. The cost and emission coefficients were also borrowed from standard sources [12] and are presented in the Appendix along with the B coefficients. Each test case was solved for its rated load condition. The solutions were obtained using three different algorithms namely non-dominated sorting genetic algorithm (NSGA-II), multi-objective differential evolution (MODE) and MOPSO. The algorithms were run in a MATLAB environment with a PC running on Microsoft windows8 platform having core i3 processor with a clock speed of 1.3GHz and RAM of 4GB.

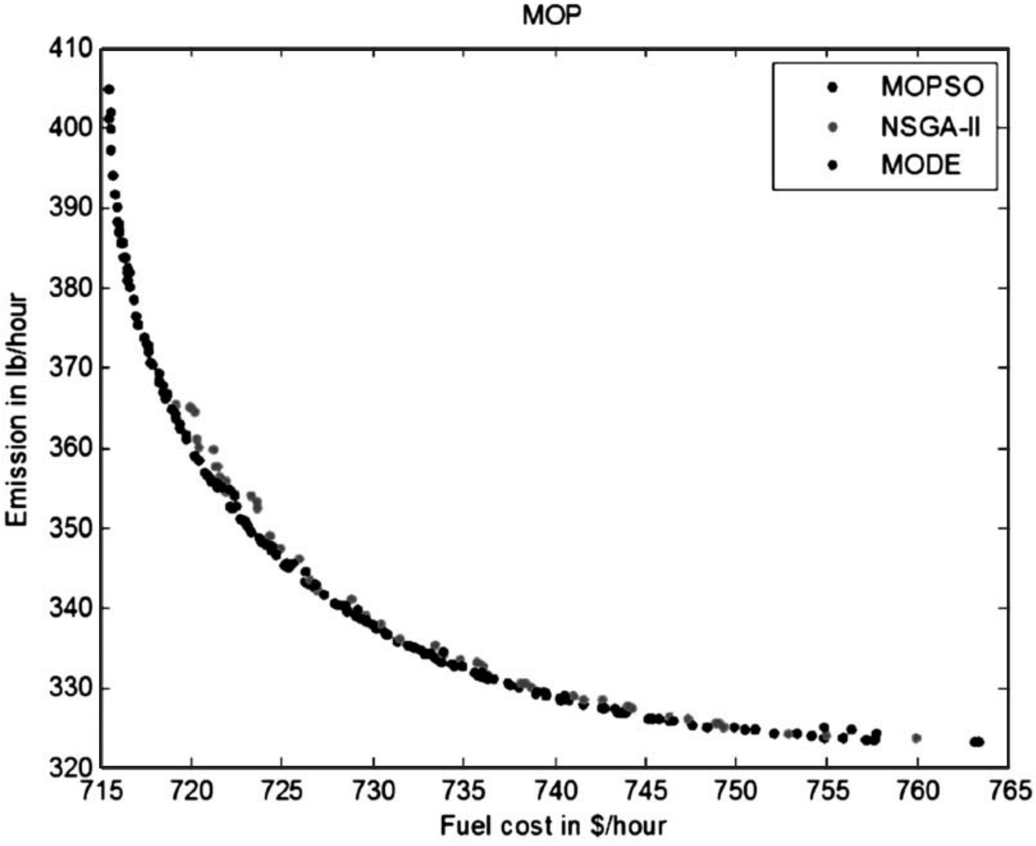

Figure 2: Solution of IEEE 14 bus system for different algorithms

The population size is taken as 100 and maximum number of generation as 300. The cross over is chosen as intermediate with ratio set as 1.2 and mutation chosen as Gaussian with a scale of 0.1 and shrink of 0.5 for NSGA-II. The scaling factor of differential evolution is set as 0.5 and Cross over rate as 0.5 with a population size of 100. The velocity weight of MOPSO is selected as 0.4 and position weights as 1 with a population size of 100 and generation of 100.

The comparative results obtained were presented in Table-1 & 2. The Pareto optimal fronts are shown in the fig.1 for the IEEE-14 bus test system. Fig.2 shows the Pareto optimal fronts obtained on the IEEE-30 bus test system.

Table 1

Results of EED of IEEE 14-bus system

Algorithm	*PG1 MW*	*PG2 MW*	*PG3 MW*	*PG4 MW*	*PG5 MW*	*Time in sec*	*Fuel Cost in $/hourt*	*Emission in lb/hour*
NSGA-II	150.416	51.3048	23.5338	23.5837	17.29	91.4121	720.3	360
MODE	130.7742	53.0186	26.3320	30.7226	24.2551	8.0020	720.1591	359.1248
MOPSO	160.3449	61.1597	33.5563	33.9973	27.8775	2.380883	720.1482	359.1649

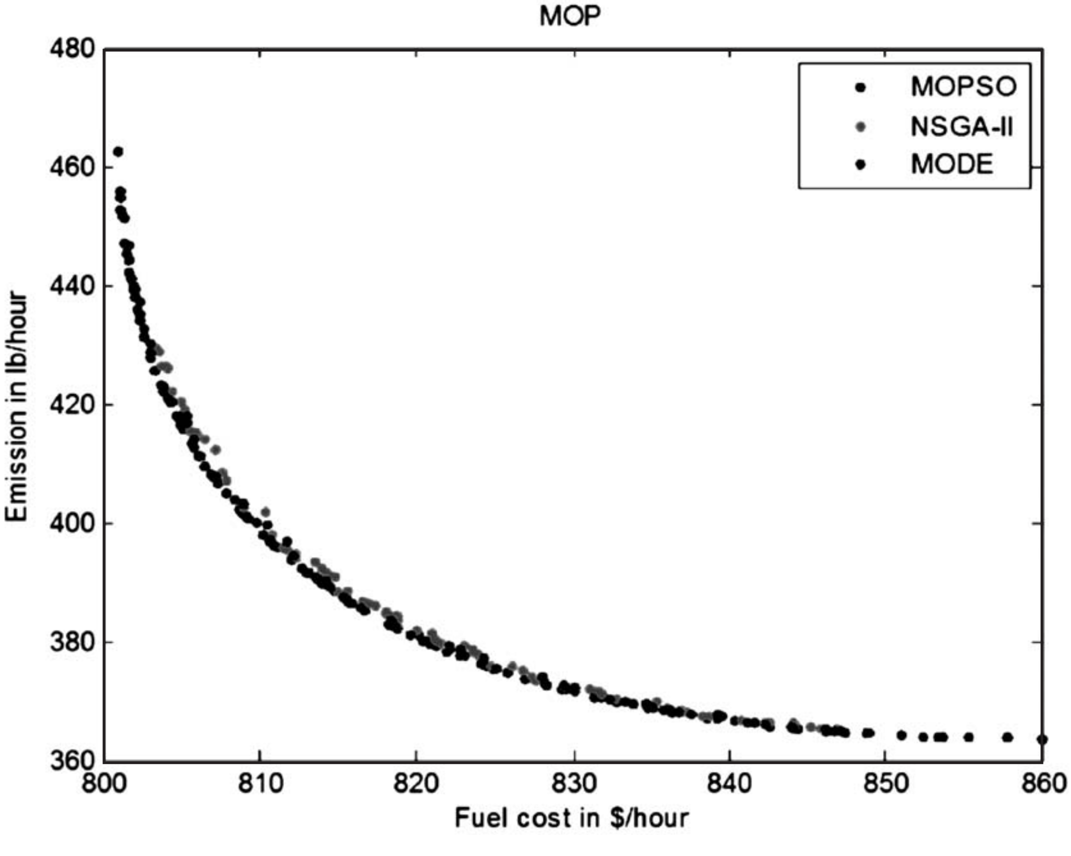

Figure 3: Solution of IEEE 30 bus system using different algorithms

It is observed that the Pareto front obtained using the MOPSO algorithm is better than the other two with respect to the solution points, their spacing, average distance and diversity of solutions (see fig.2&3). Each point on the Pareto front represents an optimum solution. However, the selection of a particular operating point is always based on the high level decision criteria like affordability, environmental norms set by local or appropriate authorities. Although, the fuel cost and emission values obtained for all the three algorithms do not differ much, the MOPSO algorithm outperforms the other two in terms of computational time (see Table-1&2).

Table 2

Results of EED of IEEE 30-bus system

Algorithm	*PG1 MW*	*PG2 MW*	*PG3 MW*	*PG4 MW*	*PG5 MW*	*PG6 MW*	*Time in sec*	*Fuel Cost in $/hour*	*Emission in lb/hour*
NSGA-II	132.672	53.443	27.719	29.870	25.102	21.916	94.5415	821.269	380.213
MODE	111.077	51.679	31.856	33.083	30	31.969	8.003	822.0048	379.5462
MOPSO	130.470	48.148	23.446	25.564	20.564	20.609	2.0302	820.5461	380.0906

5. CONCLUSION

The proposed multi-objective particle swarm optimisation algorithm has been successfully implemented for the environmental economic emission dispatch problem. The problem was solved for two test cases under rated load conditions. The performance of the algorithm have been compared with two other competitive multi-objective optimisation algorithms. There has been an improved performance on the Pareto front and hence the proposed algorithm helps in maintaining diversity of the non-dominated solution vectors. The cost and emission values obtained are consistent with those of the conventional multi-objective optimisation algorithms. The proposed MOPSO algorithm works well for the problem. This algorithm performs better with respect to computational time as compared to the other competing algorithms.

Advanced local search operators may be incorporated into the MOEAs as further research for better exploration and exploitation of the search space. There is a need for further investigation to assess the strengths and weaknesses of the proposed algorithm, so that it can be applied to other multi-objective problems in power system such as management of voltage profile and reactive power compensation etc. The performance of the proposed algorithm may also be investigated by considering other real-time constraints like ramp rate limits, power loss etc.

6. APPENDIX

Table 3

A.1 IEEE 14 Bus cost and emission coefficients

Gen No.	*Max MW*	*Min MW*	*γ*	*B*	*α*	*a*	*b*	*c*
1.	250	10	0.0126	-0.9	22.983	0.00375	2.0	0
2.	140	20	0.02	-0.1	25.313	0.0175	1.75	0
3.	100	15	0.027	-0.01	25.505	0.0625	1.0	0
4.	120	10	0.0291	-0.005	24.9	0.00834	3.25	0
5.	45	10	0.029	-0.004	24.7	0.025	3.0	0

The values of B coefficients used for the IEEE-14 bus test case are

$$B = \begin{bmatrix} 0.0208 & 0.0090 & -0.0021 & 0.0024 & 0.0006 \\ 0.0090 & 0.0168 & -0.0028 & 0.0035 & 0.0000 \\ -0.0021 & -0.0028 & 0.0207 & -0.0152 & -0.0179 \\ 0.0024 & 0.0035 & -0.0152 & 0.0763 & -0.0103 \\ -0.0006 & 0.0000 & -0.0179 & -0.0103 & 0.0476 \end{bmatrix}$$

$$B0 = \begin{bmatrix} -0.0001 & 0.0023 & -0.0012 & 0.0027 & 0.0011 \end{bmatrix}$$

$$B00 = 3.1826 \times 10^4$$

The values of B coefficients used for the IEEE-30 bus test case are

$$B = \begin{bmatrix} 0.0218 & 0.0103 & 0.0010 & -0.0025 & 0.0007 & 0.0033 \\ 0.0103 & 0.0233 & 0.0001 & -0.0043 & 0.0009 & 0.0032 \\ 0.0010 & 0.0001 & 0.0525 & -0.0380 & -0.0111 & -0.0066 \\ -0.0025 & -0.0043 & -0.0380 & 0.1011 & 0.0132 & 0.0045 \\ 0.0007 & 0.0009 & -0.0111 & 0.0132 & 0.0163 & -0.0001 \\ 0.0033 & 0.0032 & -0.0066 & 0.0045 & -0.0001 & 0.0270 \end{bmatrix}$$

$$B0 = \begin{bmatrix} -0.0002 & 0.0029 & -0.0033 & 0.0035 & 0.0016 & 0.0048 \end{bmatrix}$$

$$B00 = 0.0025$$

Table 4

A.2 IEEE 30 Bus cost and emission coefficients

Gen No.	*Max MW*	*Min MW*	*γ*	*B*	*α*	*a*	*b*	*c*
1.	200	50	0.0126	-0.9	22.983	0.00375	2.0	0
2.	80	20	0.02	-0.1	25.313	0.0175	1.7	0
3.	50	15	0.027	-0.01	25.505	0.0625	1.0	0
4.	35	10	0.0291	-0.005	24.9	0.00834	3.25	0
5.	30	10	0.029	-.0004	24.7	0.025	3.0	0
6.	40	12	0.0271	-0.0055	25.3	0.025	3.0	0

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