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EVALUATION OF DISPERSION MODELS DIPCOT AND RIMPUFF USED IN DECISION SUPPORT SYSTEMS FOR NUCLEAR AND RADIOLOGICAL EMERGENCY RESPONSE

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Abstract: This paper presents evaluation of the atmospheric dispersion models DIPCOT and RIMPUFF which are incorporated for operational use in Decision Support Systems for nuclear emergencies. The evaluation is performed through comparisons of model results with real-scale measurements of gamma radiation dose rates in air obtained during the routine operation of the HIFAR Research Reactor located in Sydney, Australia. The area surrounding the reactor is characterized by moderately complicated topography and varying land cover. A total of 16 days have been computationally simulated, covering all atmospheric stability conditions. Qualitative and quantitative model evaluation is carried out, using comparisons of paired in space and time calculated and measured gamma dose rates, statistical indices, scatter plots, and contour plots. The models performance is satisfactory for a number of cases, while for others the performance is poor. This can be attributed to a number of factors, mainly uncertainties in the prediction of meteorological conditions.

Key words: *Model evaluation, atmospheric dispersion, gamma radiation dose rate, complex terrain, emergency response*

INTRODUCTION

The atmospheric dispersion models DIPCOT (URL 1) and RIMPUFF (URL 2) are incorporated for operational use in the Decision Support System (DSS) RODOS (URL 3) for nuclear emergencies. RIMPUFF is also used in the DSS ARGOS (URL 4). The above models provide prognoses of dispersion as well as the related gamma radiation doses of accidentally released radionuclides. In this paper an evaluation exercise of DIPCOT and RIMPUFF is presented through comparisons of model-predicted with measured gamma radiation dose rates in air. Such an evaluation is of particular importance, given the potential use of the two models in the decision making process for emergency situations. The experimental data used in the evaluation were obtained from real-scale field campaigns measuring dose rates due to the routine emissions of ^{41}Ar from a research nuclear reactor. The terrain around the site was moderately complicated, with hills and valleys, with varying land cover. The available measurements were obtained during winter and summer time and covered all atmospheric stability conditions.

METHODOLOGY

Models description

Both DIPCOT and RIMPUFF are Lagrangian puff models, i.e., they simulate the release and dispersion of the radionuclides by a series of puffs, that are emitted at a point source and are transported by the wind velocity field while at the same time they grow in size due to turbulent diffusion. Concentration of nuclides in air and gamma dose rates at a particular location and time are calculated by summing the contribution of all neighbouring puffs. The differences between the two models are located in the use of meteorological fields, especially the wind velocity field, in the movement of the puffs and in the parameterization of turbulence. The necessary meteorological data that drive the dispersion are provided to DIPCOT and RIMPUFF by meteorological pre-processing codes that take as input measurements from meteorological stations. For the calculations presented in this paper, DIPCOT used the stand-alone version of the RODOS Meteorological Pre-Processor (URL 5). This code interpolates spatially in 3 dimensions the available measurements, uses semi-empirical relations for variables not measured and finally uses a divergence minimizing model to calculate a mass-consistent velocity field on a 3-dimensional terrain-following grid. RIMPUFF uses the METRODOS Meteorological Pre-processor (also called LSPAD) to obtain finely gridded met-data fields over the area of interest and to calculate parameters relating to atmospheric stability from measured meteorological tower data. The wind field for RIMPUFF is generated using an inverse square distance interpolation/extrapolation method, taking orography and surface roughness into account via a Mass Consistant Flow (MCF) code (Astrup, 2001). Regarding dispersion, DIPCOT adds a random velocity component to the mean wind speed of its particles to simulate turbulent diffusion. Both models use similarity-scaling methods (although different) of atmospheric turbulence and diffusion for the parameterisation of puffs spread.

Experimental data base

Simulations of ^{41}Ar dispersion released operationally from the HIFAR Research Reactor located in Sydney, Australia, are presented in this paper. Specifically 16 different cases are simulated that cover winter and summer periods of the years 2002 and 2003 and include all the atmospheric stability conditions. The experimental data base used for the model calculations and evaluation include the ^{41}Ar stack emission rate, measured meteorological data from 2 stations and measured gamma dose rates from 4 monitoring stations located in a radius of 5 km around the reactor. All the above data were available in 15-min time intervals. The terrain elevation and the land cover were available on a grid of 25 m resolution for the area of interest around the site. Figure 1 shows the computational domain with terrain elevation contours, the ^{41}Ar release location, the meteorological stations and the gamma dose rate detectors.The terrain is moderately complicated with hills of about 190m height and a valley that transverses the domain. The land cover is varying, including urban (south-east part), suburban (central part), woods (along the river) and low vegetation (north and south-west part) areas.

The available meteorological measurements included wind speed, wind direction and temperature at the levels of 10 and 49 m for the station Met00 and wind speed and direction at 18.5 m for the station Met01 (Figure 1). The atmospheric stability has been determined by the pre-processors for each 15-min time interval from the temperature gradient between 10 and 49m and from the wind speed.

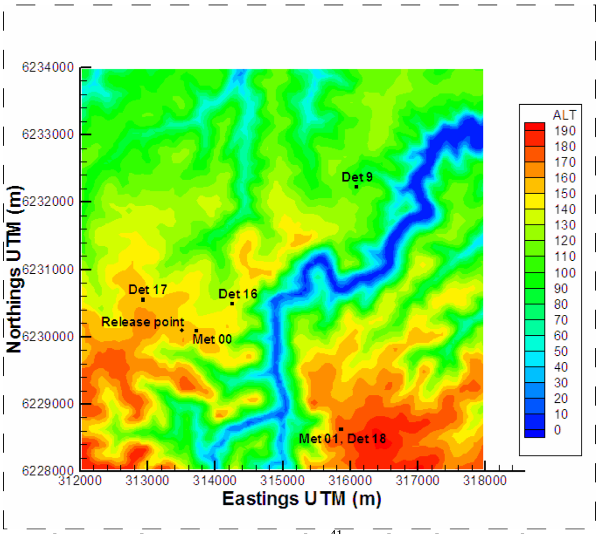

Figure 1. The computational domain with terrain elevation contours, the ^{41}Ar release location, the meteorological stations (Met00, Met01) and the gamma dose rate detectors (Det9, Det16, Det17, Det18).

RESULTS AND DISCUSSION

In Figures 2 and 3 model results are presented for the case that started at 22:15 local time of 10/6/2003, lasted for 11h and 45min and for which dose rate data were collected for Detector 16. This was a winter case with stable conditions during night time that later turned to neutral and finally unstable the next morning. Figure 2 presents the calculated dose rate for the 15-min period ending at 01:15 of 11/6/2003, which is a period with a measured peak of the dose rate. RIMPUFF predicts a much narrower, concentrated plume than DIPCOT in the stable conditions. Figure 3 presents the accumulated dose for the total simulation duration. The dose contours cover a large part of the domain due to the varying wind direction with contours of DIPCOT spreading wider than RIMPUFF.

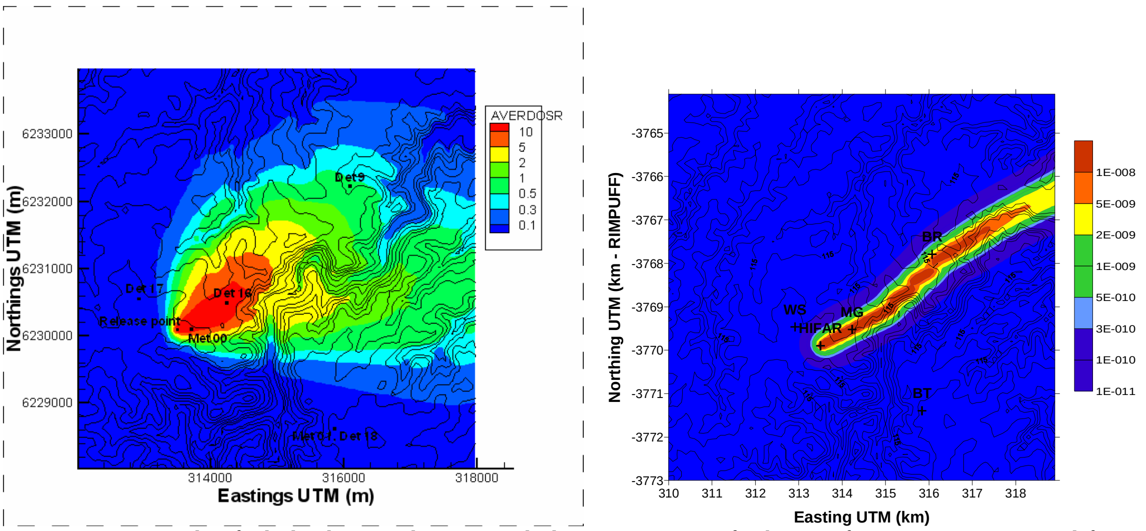

Figure 2: Contour plot of calculated gamma dose rate overlaid on terrain contours for the case of 11/6/2003 at 01:15 EST; left DIPCOT (nGy/hr), right RIMPUFF (Gy/hr)

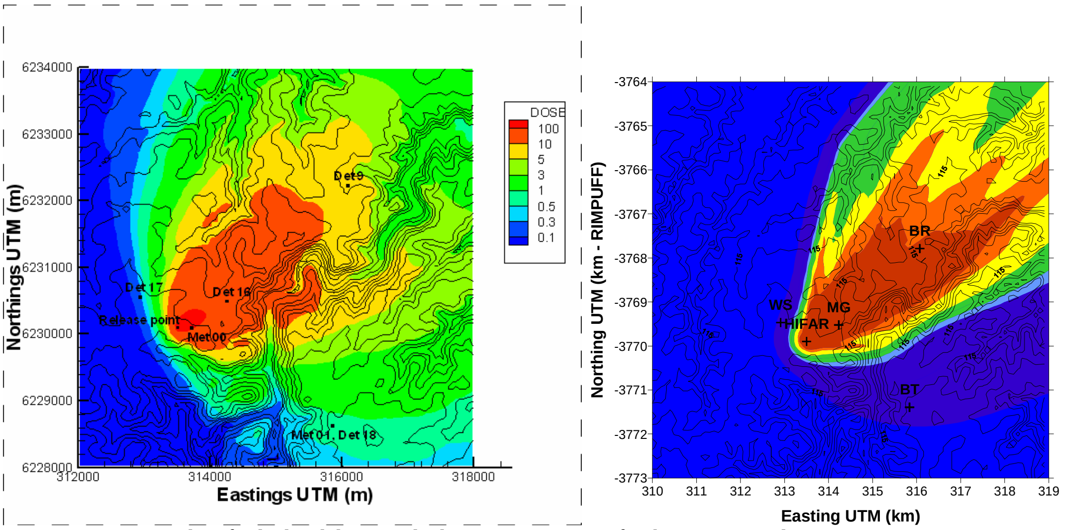

Figure 3: Contour plot of calculated dose overlaid on terrain contours for the time interval 10/6/2003, 22:30 to 11/6/2003 10:15 EST; left DIPCOT (nGy), right RIMPUFF (Gy)

In Figures 4 and 5 models results are presented for the case that started at 21:45 local time of 26/6/2003, lasted for 2h and 15min and concerned Detector 17. This was a winter case with neutral conditions. Figure 4 presents the calculated dose rate for the 15-min period ending at 23:00 of 26/6/2003. Figure 5 presents the accumulated dose for the total simulation duration. The dose contours reveal that the wind direction was varying during the simulated period.

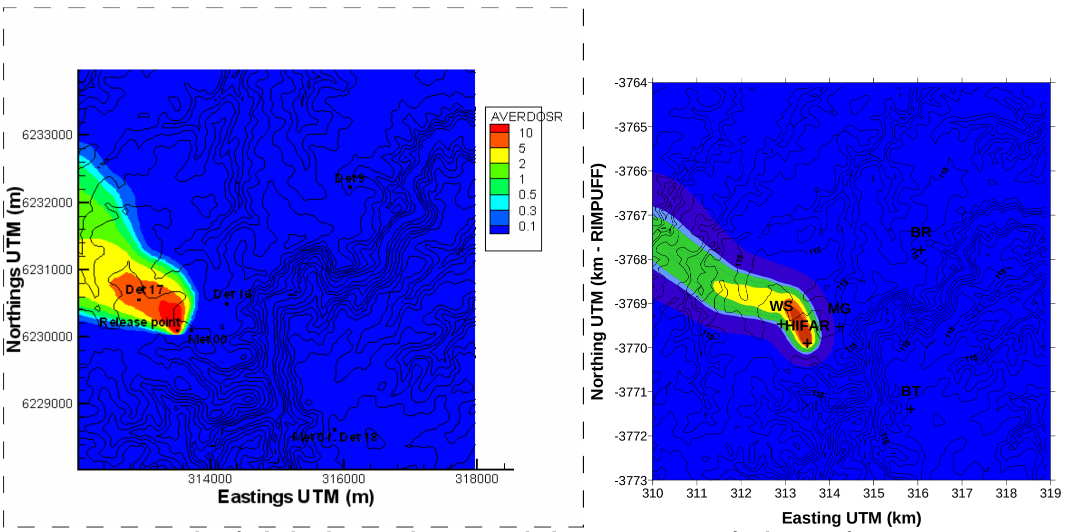

Figure 4: Contour plot of calculated gamma dose rate overlaid on terrain contours for the case of 26/6/2003 at 23:00 EST; left DIPCOT (nGy/hr), right RIMPUFF (Gy/hr)

In Figures 6 and 7 comparisons between measured and calculated gamma dose rates are presented for the cases of 25/7/2003 and 22/6/2003. The timing of the peaks is captured fairly well by the models, although in most cases of DIPCOT there is an underestimation of the measured peak values whereas RIMPUFF tends to over-predict the maximum peaks.

Quantitative evaluation of the models has been obtained through the BOOT software (Chang, J.C and S.R. Hanna, 2005) of the Model Validation Kit. Observed and calculated dose rate values, paired in space and time, have been used. A threshold value of 0.4 nGy/hr of measured dose rate has been adopted, according to the documentation of the detectors used in the field campaigns. The statistical indices have been calculated separately for each date of the experiments because it was observed that the models performance varied between cases. In Table 1 the statistical indices calculated by the BOOT software are presented. There are 5 cases for DIPCOT (25/7/03, 22/6/03, 26/6/03, 7/6/03 and 10/6/03) and 6 for RIMPUFF (25/7/03, 8/11/03, 25/11/02, 15/12/02, 29/11/02 and 7/6/03) that satisfy that suggested by the BOOT software documentation model acceptance criteria (|FB|<0.3, FA2>0.5, NMSE<1.5). It should be noted that this acceptance criteria is based on maximum concentration on arcs (i.e. unpaired in space) and model performance would be expected to deteriorate as more stringent data pairing options such as in time and space are used. There are 7 cases (6/6/03, 14/6/03, 13/6/03, 17/6/03, 9/7/03, 13/12/02 and 17/12/02) that none of the 2 models succeed in attaining the suggested satisfactory performance. Looking at the median values of NMSE, FA2 and FB for all cases, both models performance satisfies the above criteria, except the NMSE value for RIMPUFF, which indicates a rather high scatter of values. However, the FB value for RIMPUFF is very close to zero, indicating no bias in the model's predictions. The positive FB value of DIPCOT indicates a slight tendency of under-prediction by the model.

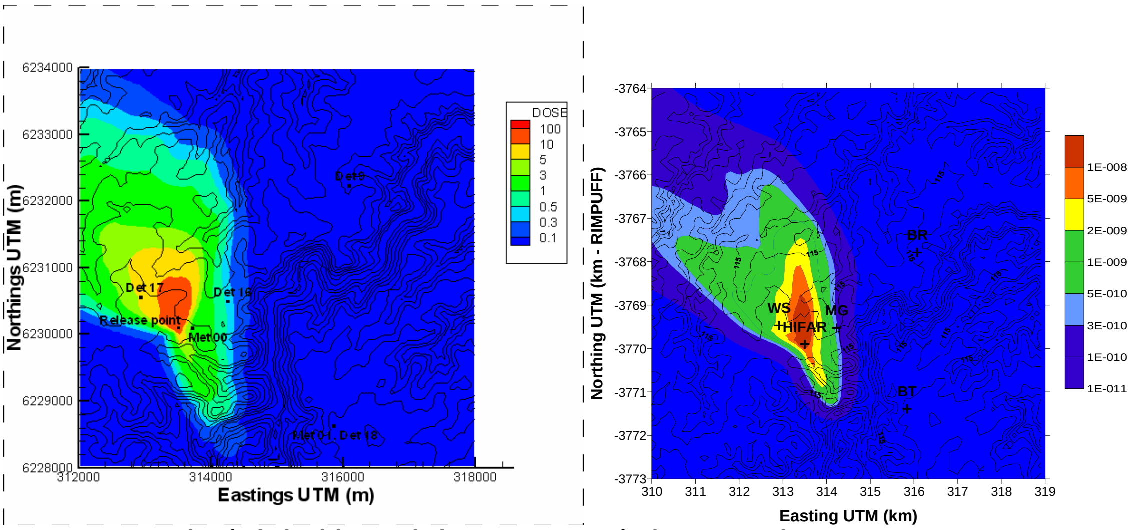

Figure 5: Contour plot of calculated dose overlaid on terrain contours for the time interval 26/6/2003, 22:30 to 27/6/2003 00:00 EST; left DIPCOT (nGy), right RIMPUFF (Gy)

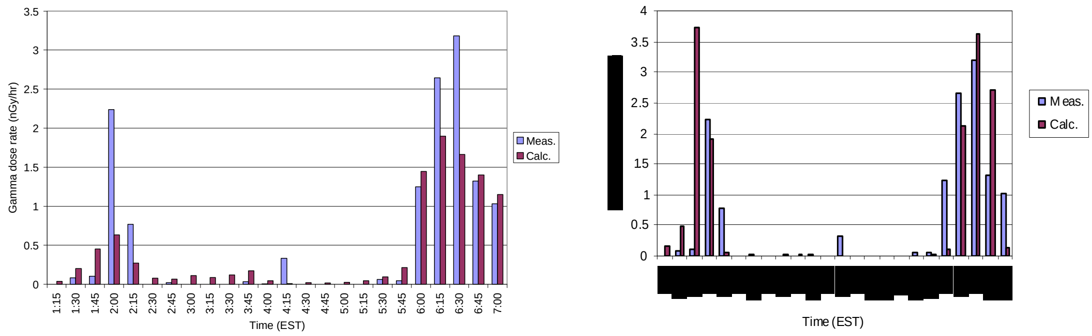

Figure 6: Comparison of measured and calculated gamma dose rates for the case of 25/7/2003

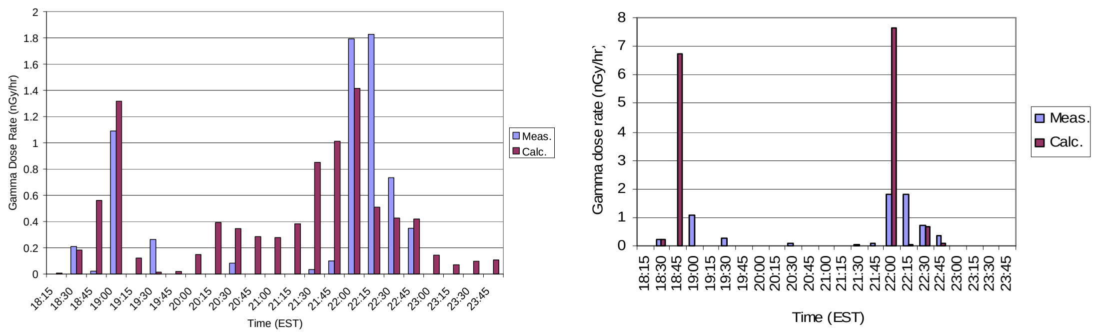

Figure 7: Comparison of measured and calculated gamma dose rates for the case of 22/6/2003

In Figure 8 scatter plots of model-calculated versus measured dose rate values are presented. It is observed that there is a large scatter of points for both models. The tendency of underestimation by DIPCOT is more evident, especially at the highest observed dose rates.

Table 1: Statistical indices for model performance obtained by BOOT software.

Case	DIPCOT				RIMPUFF			
	NMSE	CORR	FA2	FB	NMSE	CORR	FA2	FB
250703	0.46	0.81	0.93	0.28	0.78	0.61	0.73	-0.15
220603	0.46	0.48	0.73	0.07	5.61	0.34	0.64	-0.75
081103	0.69	0.88	0.82	0.37	0.86	0.09	0.82	-0.11
251102	1.52	0.63	0.42	0.71	0.44	0.78	0.75	-0.24
151202	2.10	0.90	0.57	0.81	0.50	0.71	0.86	0.26
060603	1.20	0.45	0.56	0.32	6.29	-0.21	0.44	1.27
140603	0.68	0.51	0.27	-0.46	6.52	-0.13	0.46	0.06
130603	1.34	0.23	0.33	-0.23	9.26	0.03	0.40	-0.39
260603	0.83	0.46	0.50	-0.12	3.61	-0.21	0.13	0.90
170603	4.62	0.13	0.00	1.36	1.42	0.18	0.40	0.84
090703	5.73	0.31	0.00	1.43	4.98	0.05	0.10	1.35
291102	2.16	0.79	0.80	0.30	1.07	0.81	0.80	-0.08
131202	13.11	1.00	0.80	1.26	13.11	1.00	0.80	1.26
171202	1.55	0.89	0.50	0.68	2.30	0.73	0.60	0.83
070603	0.58	0.42	0.51	0.22	0.38	0.60	0.64	0.10
100603	1.06	0.06	0.50	-0.25	3.92	0.01	0.29	-0.48
All	1.48	0.45	0.50	0.17	4.39	0.22	0.53	0.02

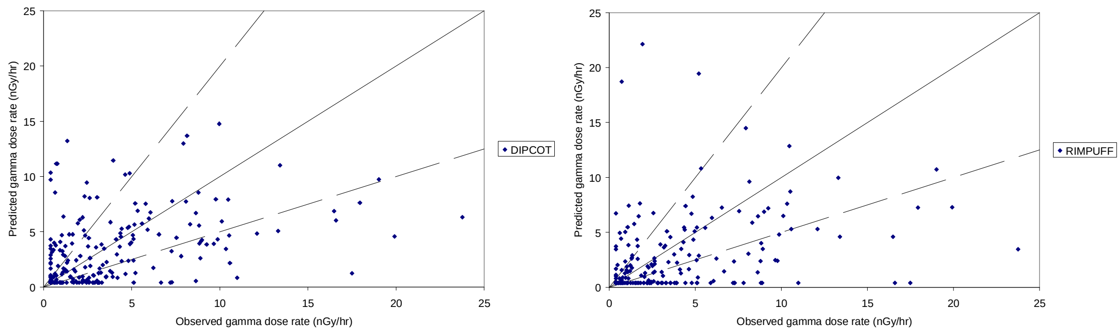

Figure 8: Scatter plot of predicted vs. observed gamma dose rates for all cases

SUMMARY AND CONCLUSIONS

An evaluation study has been presented for two atmospheric dispersion models, DIPCOT and RIMPUFF, that are both used in the frames of Decision Support Systems for Nuclear Emergencies. The evaluation has been performed through computational simulations of 16 real cases of dispersion of radioactive ^{41}Ar which is routinely released during the operation of the HIFAR research reactor in Sydney, Australia. The meteorological conditions of the cases cover the entire range of atmospheric stabilities. The terrain around the site is moderately complex with hills and valleys, while the land cover varies. Contour plots of calculated gamma radiation dose rates and accumulated doses, reveal a similar behaviour between the two models. They also show the effects of the changing wind direction during the simulated periods. The models evaluation has been performed qualitatively through comparisons of predicted and measured gamma dose rates at a number of detectors located in an area of 5km around the site. Time-history plots and scatter plots have been employed for this purpose. Quantitative model evaluation has been carried out by running the BOOT software of the Model Validation Kit with paired in space and time calculated and observed gamma dose rates. For a number of cases the models performance is satisfactory based on the values of the statistical indices, while for others it is not so. Overall the median values of the indices are within the suggested ranges according the BOOT documentation, with the exception of one value. This is a satisfactory result considering the rather strict requirement of pairing both in space and time that has been imposed for this evaluation exercise.

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URL 2: http://www.rodos.fzk.de/Documents/Public/HandbookV5/Volume3/4_2_6_RIMPUFF.pdf

URL 3: http://www.rodos.fzk.de/

URL 4: http://www.pdc.dk/Argos/decision.asp

URL 5: http://www.rodos.fzk.de/Documents/Public/HandbookV6f/Volume3/RA2TN0902_MPP.pdf