problems and Table 6.24 presents the ranking of the algorithms. Figure 6.8 provides the average, the minimum and the maximum scores for the five algorithms. In this case, each algorithm can score a maximum of 4 points and a minimum of 0 points.

Table 6.23 shows that GA, RS, SA, and TS use the extra time to improve their results significantly. For the short runs, the ranking between the different algorithms was SA > TS > HC > GA > RS. With the intensive runs, this ranking is modified and becomes SA > GA $\geq$ TS > HC > RS.

SA remains the best algorithm overall. However, GA now dominates the other competitors on under-resourced problems and reduces the gap with (SA, HC, and TS) on over-resourced problems considerably. In fact, GA and RS are the only two techniques which improve their average score. GA goes from 1.58 up to 2.27 and RS goes from 0.03 up to 0.3. HC goes from 1.91 down to 1.55, SA goes from 3.88 down to 3.6 and TS goes from 2.58 down to 2.25.

Table 6.25 shows the amount of exploration performed by the different algorithms. A comparison between Table 6.25 and Table 6.21 (which reports the same data for the short runs) underlines the considerable effort behind each intensive run. For instance, on the 30-0-0-1 problem, RS visited 33030 solutions whereas in the short run, it only had time to generate 1400 solutions. GA performed 109256 crossovers (only 4720 for the short run), HC performed 79200 cycles (only 3240 for the short run) and TS did 60600 cycles (only 3140 for the short run). This information is summarised in Figure 6.9.

Runs	GA	HC	RS	TS
short	4720	3240	1400	3140
intensive	109256	79200	33030	60600

Figure 6.9: Computational effort - Comparison between short and intensive runs.

The situation is more delicate for SA. The algorithm is performing fewer iterations

during these intensive runs. For instance, on the 30-0-0-1 problem, SA performs 142 iterations whereas in the short run, it managed 190 iterations. This is due to the fact that the number of successful moves at a given temperature went from 500 for the short runs up to 12000 for the intensive runs.

In other words, the main difference for SA between short and intensive runs is that the algorithm is given much more time to reach equilibrium at each temperature; the function used to reduce the temperature is identical in both sets of runs. Some theoretical results (see Subsection 3.3.3) suggest that this annealing schedule might not be the best option, i.e. there is no requirement to attain equilibrium at a succession of reducing temperatures, rather the main condition for a good annealing schedule is for the cooling to be carried out sufficiently slowly.

A number of alternatives for the annealing schedule can be envisaged. For instance, SA could perform only one iteration at each temperature and reduce the temperature very slowly or, at the other end of the spectrum, SA could keep the temperature constant during the search. In this case, SA would be a random search which accepts uphill moves with the probability $exp(-C\Delta)$ and C is kept constant during the search.

In conclusion, there is no overall champion among the five algorithms which all benefit from the longer runs. Typically, GA takes advantage of the extra computational effort to provide the best solutions on under-resourced problems. Again, SA is a robust technique which performs well both on under-resourced and over-resourced problems.

	GA	HC	RS	SA	TS
30-0-0-1	418611	744850	950471	389783	433014
30-0-0-2	191802	521610	747099	193632	240439
30-0-0-3	91073	372232	585131	107356	114528
30-0-3-1	255015	597360	720178	314549	273084
30-0-3-2	283818	618848	770597	337931	312673
30-0-3-3	611376	924910	1060289	609596	605968
30-2-0-1	483638	757418	862319	489156	499902
30-2-0-2	485557	649270	740012	449042	459864
30-2-0-3	1327704	1520217	1483255	1339915	1345469
30-2-3-1	1016668	1382046	1314405	1041505	1054138
30-2-3-2	725090	1185889	1112688	750395	739479
30-2-3-3	608013	915757	846271	641898	645515
40-0-0-1	914	857	2203	696	1095
40-0-0-2	872	811	2186	687	1146
40-0-0-3	843	738	2136	671	1053
40-0-3-1	1122	1006	2245	868	1114
40-0-3-2	1090	1063	2148	821	1022
40-0-3-3	1156	1042	2341	913	1150
40-2-0-1	271441	557247	416225	238547	233278
40-2-0-2	1350	74777	27472	807	924
40-2-0-3	1312	91005	20370	853	1004
40-2-3-1	1556	55287	2494	1063	1085
40-2-3-2	1484	13784	2196	953	981
40-2-3-3	1733	278488	148155	1084	1164
50-0-0-1	945	849	2248	727	1175
50-0-0-2	895	750	2163	714	1163
50-0-0-3	862	719	2171	673	1122
50-0-3-1	1161	1030	2234	876	1176
50-0-3-2	1139	1033	2284	905	1158
50-0-3-3	1150	965	2260	889	1116
50-2-0-1	1260	919	2151	883	1063
50-2-0-2	1073	784	2032	699	962
50-2-0-3	1169	904	2074	818	999
50-2-3-1	1377	1092	2141	939	971
50-2-3-2	1561	10286	2333	1055	1099
50-2-3-3	1498	1271	2337	1028	1061

Table 6.23: 4 hour runs - Average final cost.

	GA	HC	RS	SA	TS
30-0-0-1	3	1	0	4	2
30-0-0-2	4	1	0	3	2
30-0-0-3	4	1	0	3	2
30-0-3-1	4	1	0	2	3
30-0-3-2	4	1	0	2	3
30-0-3-3	2	1	0	3	4
30-2-0-1	4	1	0	3	2
30-2-0-2	2	1	0	4	3
30-2-0-3	4	0	1	3	2
30-2-3-1	4	0	1	3	2
30-2-3-2	4	0	1	2	3
30-2-3-3	4	0	1	3	2
40-0-0-1	2	3	0	4	1
40-0-0-2	2	3	0	4	1
40-0-0-3	2	3	0	4	1
40-0-3-1	1	3	0	4	2
40-0-3-2	1	2	0	4	3
40-0-3-3	1	3	0	4	2
40-2-0-1	2	0	1	3	4
40-2-0-2	2	0	1	4	3
40-2-0-3	2	0	1	4	3
40-2-3-1	2	0	1	4	3
40-2-3-2	2	0	1	4	3
40-2-3-3	2	0	1	4	3
50-0-0-1	2	3	0	4	1
50-0-0-2	2	3	0	4	1
50-0-0-3	2	3	0	4	1
50-0-3-1	2	3	0	4	1
50-0-3-2	2	3	0	4	1
50-0-3-3	1	3	0	4	2
50-2-0-1	1	3	0	4	2
50-2-0-2	1	3	0	4	2
50-2-0-3	1	3	0	4	2
50-2-3-1	1	2	0	4	3
50-2-3-2	2	0	1	4	3
50-2-3-3	1	2	0	4	3

Table 6.24: 4 hour runs - Ranking of the search techniques.

	GA	HC	RS	SA	TS
30-0-0-1	109256	79200	33030	142	60600
30-0-0-2	157880	79120	33170	138	66200
30-0-0-3	229604	75920	33020	138	65200
30-0-3-1	262948	278480	108310	458	230400
30-0-3-2	291840	281040	107060	516	214800
30-0-3-3	244428	282000	111510	412	231200
30-2-0-1	97960	90560	33650	134	69600
30-2-0-2	103164	127600	34430	224	126800
30-2-0-3	54596	210080	36640	370	149000
30-2-3-1	193360	415840	114750	654	256000
30-2-3-2	228748	371840	117620	530	232600
30-2-3-3	224460	432960	128630	762	318600
40-0-0-1	365912	395680	32500	908	535800
40-0-0-2	362880	418560	33060	1036	565200
40-0-0-3	356580	374000	32750	932	527000
40-0-3-1	439100	512480	109030	1196	589200
40-0-3-2	447996	468080	109530	1180	563800
40-0-3-3	432684	533840	115310	1210	574600
40-2-0-1	174048	260160	35370	930	285000
40-2-0-2	409540	265760	35040	1000	347400
40-2-0-3	441248	240000	35090	952	332600
40-2-3-1	559396	444240	112230	1176	491200
40-2-3-2	515452	408720	112340	1132	471800
40-2-3-3	537916	409600	102640	1052	414800
50-0-0-1	361508	502400	32170	1216	583000
50-0-0-2	351576	531840	32140	1242	589200
50-0-0-3	326192	550880	32500	1278	612800
50-0-3-1	435360	622560	102480	1374	609000
50-0-3-2	442340	599040	104440	1382	622800
50-0-3-3	446072	603680	107210	1334	628400
50-2-0-1	477620	414800	34920	1324	426400
50-2-0-2	483448	540000	33800	1362	496600
50-2-0-3	479948	398560	34690	1306	425400
50-2-3-1	543000	513520	107820	1466	522200
50-2-3-2	546856	453040	96760	1456	489200
50-2-3-3	523348	521280	116650	1426	537800

Table 6.25: 4 hour runs - Amount of exploration.

Chapter 7

Conclusion.

This chapter summarises the work that has been presented, discusses areas of future work, and finally concludes this thesis.

7.1 Summary.

The growing complexity of telecommunications networks means that their management is also becoming more and more complicated. Due to several factors, e.g. amount of data, inconsistent and incoherent data, and time constraints, Artificial Intelligence techniques will be essential in order to carry out some of the management functions.

This thesis focuses on one particular aspect of network management: resource management. The key-motivation behind this work is two-fold:

- It is essential for the telecommunications operators to solve their resource allocations problems in an efficient manner.
- Many classical techniques are inadequate because, due to the sheer size of the

problems encountered, they cannot provide an answer in reasonable time.

Genetic algorithms have been proposed as a possible alternative. However, traditional indirect GAs are not suitable in many cases because they are too slow or too disruptive. To answer these limitations, this thesis proposes a new class of GAs which works directly on the chromosomes. In other words, the solutions are the chromosomes, the GA is no longer working with an indirect representation.

This thesis offers three large empirical studies which observe the performance of these direct GAs, and compare their performance against those of other search techniques in the context of workforce management. A set of thirty six problems is used for these observations and comparisons; each problem is radically different from the rest. More precisely, the effects of three parameters have been studied: work load, time windows, and specialisation constraints. A problem can be under-resourced, critically-resourced, or over-resourced, time windows can either be loose or tight, and specialisation constraints can also be either loose or tight. These three parameters and their possible values mean that there are twelve different configurations, and for each configuration, there are three randomly generated problems. Hence, the thirty six problems. Empirical evidence shows that *work load* is a key-parameter, which decides how the algorithms perform, i.e. determines whether all the work will be done or some will remain undone.

The two chromosomal representations, direct and indirect, are compared, and it is shown that the direct GAs totally dominate the indirect GA, both in terms of quality of solution and amount of exploration. The average costs achieved by the indirect GA are in fact remarkably similar to those achieved by RS and clearly, the association of *order-based GA and schedule-builder* is not suitable for this type of problem; the indirect GA is not guiding its search properly. In general, the steady state model performs better than the generational model.

When the problem under study is over-resourced, a more adaptable random-based

crossover operator should be chosen; however, for an under- or critically-resourced problem, the knowledge-based crossover which tries to maximise the amount of work done should be preferred. This study also shows that increasing population size and diversity helps the search process, but maintaining diversity within the population is no easy task. As the population size increases, the probability of producing duplicates increases, and the efforts to produce novel chromosomal material can be expensive. This also suggests that producing the initial population via a *smart* schedule-builder may lead to a loss of diversity and a poor GA performance. A possible alternative may be to seed the initial population, the algorithm will then have access to a limited set of above-average solutions and at the same time, the level of diversity will not be too severely affected.

Then, the GA is equipped with a repair algorithm. For each child created, the repair algorithm uses a TSP heuristic to improve the different tours and then tries to insert un-allocated jobs in the schedule, where the heuristic has created some empty slots. In general, this association of GA and repair algorithm is fruitful, particularly on over-resourced problems. Due to the increased computational effort, some exploration is lost. This suggests that GAs may benefit from extended runs.

In the 10 minute beauty contest, SA dominates the other competitors, performing well on all problems. GA works fairly well on under-resourced problems; however, it is outperformed by HC, SA, and TS on over-resourced problems; mainly because GA cannot "reduce travel" as well as its three opponents. Again, the results suggest that GA would benefit from extended runs.

The CPU intensive experiments (4 hour CPU instead of 10 minutes) show that indeed GA benefits from more CPU time, and on under-resourced problems, GA generally outperforms all of the other techniques. Again, SA is a robust technique which performs well both with under-resourced and over-resourced problems. The fact that SA is more adaptable than GA should not be unexpected. The internal algorithm of GA has been designed to maximise the amount of work done, this

complex internal algorithm is not as adaptable as the simpler SA.

On a more general note, when comparing search techniques, the amount of time spent implementing them should be taken into consideration. In this study, the implementation and the tuning of SA took less time - several weeks less - than for GA. Hence, with respect to that particular criterion, SA is again dominant. Moreover, HC, RS, SA and TS all require much less memory than GA. While these four algorithms can work with a minimum of two solutions, i.e. the current solution and the best solution, GA requires an entire population. This situation can only become worse when the size of the problem increases.

Therefore, from this study, it appears that in many cases, SA should be preferred. For instance, this study advocates SA when the algorithm is only given a limited amount of time, i.e. in this case, 10 minutes, or when the VRP is over-resourced.

On the other hand, GA with a knowledge-based crossover should be adopted - when CPU time is available - for the solution of under-resourced VRPs. Out of the five search techniques studied in this thesis, direct GA is the most knowledge-based. On hard problems, and when given enough time, GA uses this extra information to provide the best solutions. This suggests that direct GA, using the correct parameters (e.g. cost, profit) to preserve the best parts of the solutions, could be used to solve highly constrained problems. SA, and also TS, would be preferable for lightly constrained problems.

7.2 Future work.

This work can now proceed in a number of ways:

- Apply stochastic techniques to other more telecommunications-oriented problem-domains

- Consider several objective functions rather than only one
- Consider dynamic problems rather than static problems
- Consider a distributed and cooperative approach
- Integrate the search algorithms with a graphical user interface

7.2.1 Stochastic techniques and other problem-domains.

First, it may be preferable to mention where these stochastic techniques will not be of any use. At the lowest levels in the management hierarchy, AI techniques will be used on-line in order to accelerate the control process and reduce human intervention. This will not be achieved with GA, HC, RS, SA or TS. These techniques are iterative and thus, they cannot be considered for such fast control tasks. Rather, neural networks may be the answer with their parallel architecture and hardware implementations.

Stochastic techniques will be in demand at the highest levels in the management hierarchy, where they will be used to solve different classes of resource allocation problems: not only work force management problems but also frequency allocation problems, design and dimensioning problems, or virtual path management problems in ATM networks.

For instance, a heuristic algorithm has been proposed to solve the virtual path management problem [LOGO92]. This suggests that stochastic techniques such as GA or SA could also be applied to this particular problem.

The next paragraphs define the virtual path management problem and show how stochastic techniques could be used to tackle this particular problem.

ATM is the multiplexing and switching technology adopted by ITU-TSS for the future Broadband Integrated Services Digital Network (BISDN). ATM is a connection-

oriented technology, i.e. no information may be transferred between the users until a connection is established. Such a connection in ATM is referred to as a virtual channel (VC). In turn, these VCs are grouped into virtual paths (VPs). To be precise, a VP is a bundle of VCs that have the same end-points. Virtual paths provides a flexible logical network on top of the physical network.

Virtual path management is responsible for creating, maintaining, releasing, and modifying the network of virtual paths. It becomes necessary to modify the existing virtual paths when some of them experience unacceptably high levels of call rejection. Typically, two strategies can be used:

- If only a small modification is required, then only the bandwidths of the VPs are modified. This method is called bandwidth re-allocation. The virtual path manager re-allocates dynamically the bandwidth among the different paths.
- If a larger modification is necessary, the routes of the VPs also have to be modified. It then becomes a routing problem.

These two functions - bandwidth re-allocation and routing - can be performed at the network level by a central operations system. This operations system collects traffic load and VP (bandwidths and routes) information for the entire network, applies a heuristic to this information and generates the appropriate control actions. Then, the new routing tables and/or the new bandwidth allocations are down-loaded to the different nodes of the network. Stochastic techniques working as meta-heuristics could be associated with this heuristic in order to guide its search and improve its performance.

7.2.2 The objective function is a parameter.

As already mentioned in Section 3.1, The objective function plays an essential part in the search by judging the quality of the candidate solutions and hence, by guiding the search process in its exploration. Management problems can have many - possibly conflicting - objectives: minimise the worst blocking probability, maintain fairness, balance load, maximise throughput, maintain robustness, minimise delays. Therefore, a future study should consider the objective function as a parameter and study its effects on the different algorithms.

7.2.3 Dynamic problems.

The techniques presented in this thesis were designed to tackle static problems; they do not respond to changes in the environment. Different events may occur within a dynamic environment, such as the modification or deletion of a job, the addition of a resource. A scheduling system must address these different situations.

Solving a dynamic problem can be regarded as solving a static problem of the same class, many times in succession. Hence, a dynamic algorithm would have to solve a succession of complex resource allocation problems. Rather than starting from scratch all the time, the ideal technique would be to repair the current solution and make it consistent with the new problem. Moreover, the solutions should be made *robust* so that, when a modification in the environment occurs, the solution requires little repair [DRUM92].

7.2.4 A distributed and cooperative approach.

Here, the problem is no longer solved by a single agent, rather the problem is given to a number of agents; each agent is able to solve the problem entirely on

its own. Agents can communicate during the search. Once an agent has found a good solution, the solution is transferred to the other agents which can use this information to guide and direct their search in the most promising areas of the search space [1]. The decision to adopt such a distributed and cooperative approach could bring many benefits:

1. Clearwater et al. [CLEA91] report that a set of cooperative agents solving a common cryptarithmetic problem [2] can achieve a combinatorial implosion, i.e. a super-linear speed-up with respect to the number of agents. This speed-up is due to the cooperation between the agents and the specific nature of cryptarithmetic problems. In the context of VRPs, a distributed system might not achieve such a formidable speed-up. An important objective for future experiments will be to determine if (as expected) cooperation among, say, n agents enables a faster search than n individual agents working separately. Future experiments should also examine the effects of different communications strategies. For instance, a distributed system could have a star topology with a central server controlling the flow of messages between all the agents. On the other hand, the different agents could be fully connected - or they could use a ring topology - and be able to communicate without the assistance of a central controller.

2. A problem can be solved from different perspectives. Agents may employ different algorithms, focus on different objectives [3] and hence, come up with

[1] For example, when a GA receives a solution sent by another agent, this solution is evaluated and inserted in the local population. If the solution manages an above-average score, it is likely that this solution will participate to a number of crossover operations. In a sense, this technique performs the same function as the search intensification module of TS.

[2] A cryptarithmetic problem can be viewed as a constraint satisfaction problem. A typical example of such problems is given by the sum $DONALD + GERALD = ROBERT$. The task is to find unique digit assignments to each of the letters so that the numbers add up correctly. For this example, the only solution is $A = 4, B = 3, D = 5, E = 9, G = 1, L = 8, N = 6, 0 = 2, R = 7, T = 0$.

[3] Observe that communications between two agents using totally different perspectives may be meaningless.

radically different answers at the end. Either the system can attempt to manipulate and integrate these answers or leave the user decide which solution best suits the problem. Such a system would be more adaptable. In a single-agent system, if the agent finds a problem hard to solve, there is no alternative whereas if an agent fails to solve the problem properly in a multi-agent system, the other agents may be able to provide a better answer.

3. It can also provide an *any-time* system, i.e. a system which can deliver a solution at any-time. The agents can solve the problem at different levels of granularity. Some agents, i.e. the shallow agents, may attempt to provide fast non-optimal solutions whereas other agents, i.e. the deep agents, may require more processing but deliver solutions of better quality. With these multiple levels of reasoning, the overall system can provide an answer at any time. The quality of this answer increases with time as deep agents terminate their search. For instance, for the solution of under-resourced problems, such a system could incorporate GA-based and SA-based agents, the SA-based agents would provide good quality solutions at the early stages of the search, and later on, the GA-based agents could provide better solutions.

7.2.5 Integration with a graphical user interface.

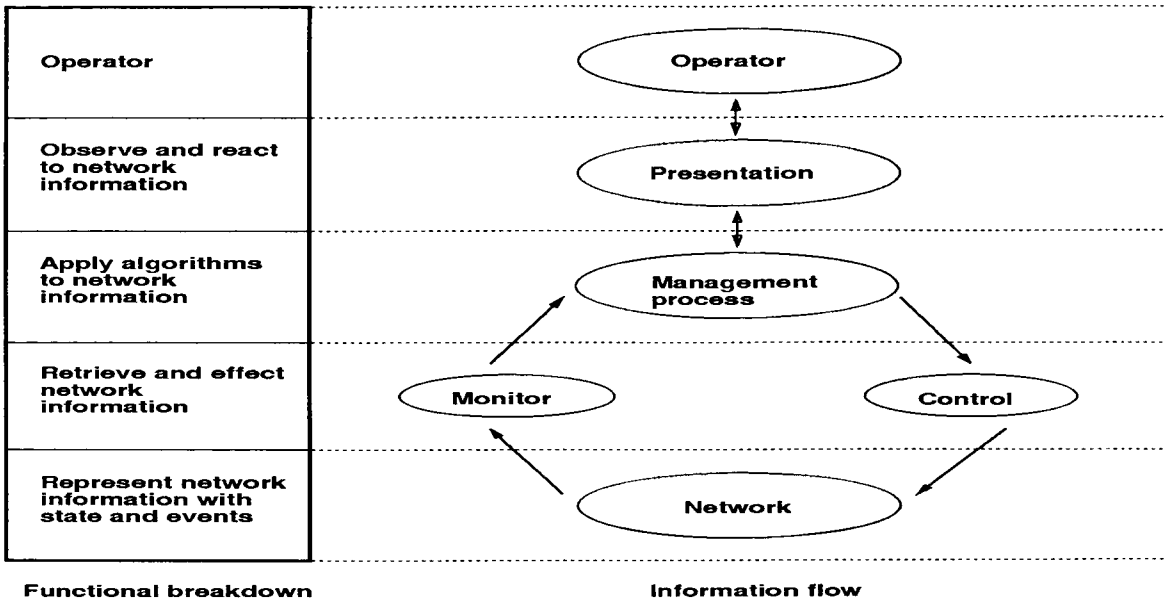
Finally, the last step in the development of a complete management system may be the integration of these different search techniques with a graphical user interface (GUI).

The management process would be broken into two modules (see Figure 7.1) [CRUT93]:

1. The process module would monitor the state of the network and generate the appropriate actions.

2. The presentation module would play an essential part by filtering the infor-

mation presented to the operator and by allowing the operator to interact directly with the network.



From: "Management and control for giant gigabit networks", by L.Crutcher and A.A.Lazar, IEEE Network, November 1993.

Figure 7.1: Management system: observation, control, and presentation.

The GUI could follow the Seeheim model[4] [GREE85], already used in a previous project [MULL92]. This model divides the interface into three layers: the presentation layer defines the presentation components, the dialogue layer monitors the dialogue between the user and the application and checks for consistency, and the application layer receives messages from the dialogue layer and activates the corresponding function of the internal application using a message-passing mechanism.

The operator will be able to view the management problem at different levels of abstraction, e.g. call, path, physical link and network levels. The use of object-oriented techniques will give the opportunity to implement a number of sophisticated mechanisms such as direct manipulation and direct observation.

[4]This model has been employed by the ESPRIT project "VITAMIN" (VIsualisation sTAndard tools in Manufacturing INdustry) for the development of industrial application-interfaces in Computer Integrated Manufacturing (CIM).

Direct manipulation means that the user is able to manipulate any network element directly from his/her terminal by manipulating the graphical object which represents this network element. The manipulations are translated automatically into internal function calls by the interface itself and direct observation means that the information on the screen is automatically updated whenever the internal data is altered, thus allowing a continuous representation of the data of interest and also allowing the user to observe immediately the consequences of his/her actions on the screen.

This GUI equipped with its sophisticated mechanisms will give the opportunity to the operator to interact in an efficient manner with the internal application and the physical network.

7.3 Concluding remark.

This thesis has reported and discussed the results of three large empirical studies. The main objective here was to study how a new class of GAs perform. The breadth of this study was essential if any useful knowledge was to be gained about the applicability of stochastic techniques - in, particular, direct GAs - to vehicle routing problems. A study on a smaller scale would only have distorted the results.

More generally, many AI techniques are still in their infancy and large empirical studies such as the one provided in this thesis are essential in order to gain a better understanding of these techniques and how they can be applied to telecommunications problems.

It cannot be expected that one AI technique will dominate all the other techniques on all the problems. More likely, each technique will have its own *territory*. Therefore, such large empirical studies are essential to define which technique is best for which class of problem and to be able - for a given problem - to anticipate the

behaviour of the different techniques and the quality of their answers.

Bibliography

[ADEN92] B. Adenso-Diaz. Restricted neighbourhood in the tabu search for the flowshop problem. *European Journal of Operational Research*, 62, pages 27-37, 1992.

[BAGC91] S. Bagchi, S. Uckum, Y. Miyabe, and K. Kawamura. Exploring problem-specific recombination operators for job shop scheduling. In *[ICGA91]*.

[BELL93] E. Bell. Telecommunications: telephony merges with video. *IEEE Spectrum*, January 1993.

[BLAN93] J. L. Blanton and R.L. Wainwright. Multiple vehicle routing with time and capacity constraints using genetic algorithms. In *[ICGA93]*.

[BODE90] A. Boden. *The social impact of thinking machines*, pages 95–103. Blackwell, 1990.

[BRIN94] C. Brind, C. Muller, and P. Prosser. A study of stochastic search techniques applied to vehicle routing problems - Part 2. *BT report*, University of Strathclyde, June 1994.

[BRUN93] R. Bruns. Direct chromosome representation and advanced genetic operators for production scheduling. In *[ICGA93]*.

[BURK91] P. Burke and P. Prosser. A distributed asynchronous system for predictive and reactive scheduling. *The International Journal for Artificial Intelligence in Engineering*, 6(3), July 1991.

[CCIT88] CCITT. Recommendation M.30, principles for a telecommunications management network. In Blue book, general maintenance principles. Maintenance of international transmissions systems and telephone circuits, Volume IV.1, pages 22–61, 1988.

[CEBU89] K. Cebulka, M. Muller, and C. Riley. Applications of artificial intelligence for meeting network management challenges in the 1990's. *IEEE Globecom'89.*

[CERN85] V. Cerny. Thermodynamical approach to the traveling salesman problem: an efficient simulation algorithm. *Journal of Optimisation Theory and Applications*, 45:41–51, 1985.

[CHAI92] B. Chaib-Draa, J. Moulin, R. Mandiau, and G. Millot. Trends in distributed artificial intelligence. *Artificial Intelligence Review*, 6(1), 1992.

[CLEA91] S.C. Clearwater, B.A. Huberman, and T. Hogg. Cooperative solution of constraint satisfaction problems. *Science*, 254:1181-1183, 22 November 1991.

[CLEV89] A. Cleveland and S.F. Smith. Using genetic algorithms to schedule flow shop releases. In *[ICGA89].*

[CLIT89] P. Clitherow and G. Fisher. Knowledge based assistance of genetic search in large design spaces. In *IEA/AIE-89: Proceedings of the Second International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems*, volume 2, pages 729–734, ACM.

[COMM92a] ISS generate info network consortium agreement. *Communications International*, December 1992.

[COMM92b] AT&T back in the local loop. *Communications International*, December 1992.

[CONN88] D.T. Connolly. An improved annealing scheme for the QAP. *European Journal of Operational Research*, 46:93–100, 1988.

[COX91] L.A. Cox, L. Davis, and Y. Qiu. Dynamic anticipatory routing in circuit-switched telecommunications networks. In *[DAVI91b].*

[CRUT93] L. Crutcher and A. Lazar. Management and control for giant gigabit networks. IEEE Network, pages 62-71, November 1993.

[DAVI91a] Y. Davidor. *Genetic algorithms and robotics: a heuristic strategy for optimization.* World Scientific Series in Robotics and Automated Systems (Volume 1). Singapore: World Scientific, 1991.

[DAVI85a] L. Davis. Applying adaptive algorithms to epistatic domains. In *Proc International Joint Conference on Artificial Intelligence*, 1985.

[DAVI85b] L. Davis. Job shop scheduling with genetic algorithms. In *[ICGA85].*

[DAVI87] L. Davis, editor. *Genetic algorithms and simulated annealing.* Morgan Kaufmann, 1987.

[DAVI91b] L. Davis, editor. *Handbook of genetic algorithms.* Van Nostrand Reinhold, 1991.

[DEWE89] D. de Werra and A. Hertz. Tabu search techniques: a tutorial and an application to neural networks. *OR Spektrum*, 11:131-141, 1989.

[DIZA89] W.P. Dizard. *The coming information age: an overview of technology, economics and politics.* Longman, third edition, 1989.

[DRUM92] M. Drummond. Practical approaches to scheduling and planning. AAAI 1992 Spring Symposium Series Reports, page 26, AI magazine, Volume 13, No 3, Fall 1992.

[DUBR93] S. Dubreuil. Les 100 qui font les telecoms dans le monde. *Telecoms Magazine*, November 1993 (in French).

[ECON92a] Developing cross-border European telecommunications. *The Economist*, (14th, 20th), November 1992 (advertisement feature for Northern Telecom).

[ECON92b] The turning of telecoms. *The Economist*, (14th, 20th), November 1992.

[ECON92c] The big break. *The Economist*, (14th, 20th), November 1992.

[ECON93a] British Telecom and EDS. *The Economist*, (6th-12th), February 1993.

[ECON93b] Baby Bells and cable TV. *The Economist*, (6th, 12th), February 1993.

[ECON93c] VISA international, digital credit. *The Economist*, (25th, 2nd), September 1993.

[ECON94] SPRINT and EDS, party line. *The Economist*, (21st, 27th), May 1994.

[EGLE90] R.W. Eglese. Simulated annealing: a tool for operational research. *European Journal of Operational Research*, 46:271–281, 1990.

[EMBR90] C. Embry,A. Manson, and F. Milham. An open management architecture: OSI/NM forum architecture and concepts. *IEEE Network Magazine*, July 1990.

[ERCA91] J. Ercau and J. Ferber. L'intelligence artificielle distribuée. *La Recherche*, 22(233), June 1991 (in French).

[FAGA93] M. Fagan. Electricity firms make a threatening connection. *The Independent*, Wednesday 10th November 1993.

[FAIG92] U. Faigle and W. Kern. Some convergence results for probalistic tabu search. *ORSA Journal on Computing*, 4:1,32-37, 1992.

[FAIR91] M. Fairley. Network management (a tutorial). *Third IEE Conference on Telecommunications, Edinburgh*, March 1991, IEE.

[FITC91] A. Fitchett and H. Reeve. Future challenges for network management. *British Telecommunications Engineering Journal*, 10, October 1991.

[FOX84] M. S. Fox and S. .F. Smith. ISIS, a knowledge-based system for facturing scheduling. *Expert systems* , Vol 1, Part 1, pages 25-49, 1984.

[GARE79] M. Garey and D. Johnson. *Computers and intractability: a guide to the theory of NP-completeness.* W.H. Freeman, 1979.

[GARI92] J. Garijo and D.A. Hoffman. A multi-agent architecture for operation and maintenance of telecommunication networks. In *12th International Conference on Expert Systems and their Applications*, Avignon'92, 1992.

[GASS89] L. Gasser. Distributed artificial intelligence. *AI Expert*, July 1989.

[GLOV87] D.E. Glover. Solving a complex keyboard configuration problem through generalized adaptive search. In *[DAVI87].*

[GLOV86] F. Glover. Future paths for Integer Programming and links to Artificial Intelligence. *Comp Oper Res*, 13:533-549, 1986.

[GLOV88] F. Glover. Tabu Search. *CAAI Report 88-3*, University of Colorado, Boulder, 1988.

[GLOV89a] F. Glover. Tabu Search, Part I. *ORSA Journal on Computing*, 1:3, 190-206, 1989.

[GLOV89b] F. Glover and H. J. Greenberg. New approaches for heuristic search: a new bilateral linkage with artificial intelligence. *European Journal of Operational Research*, 39:119-130, 1989.

[GOLD85] D. E. Goldberg and R. Lingle. Alleles, loci, and the traveling salesman problem. In *[ICGA85]*.

[GOLD86] B.L. Golden and C.C. Skiscim. Using simulated annealing to solve routing and location problems. *Naval Research Logistics Quaterly*, 33:261–279, 1986.

[GREE85] M.Green. Report on dialogue specification tools. InUser-interface Management System, G.E.Pfaff (editor), Springer-Verlag, pages 9-20, 1985.

[GREF87] J. J. Grefenstette. Incorporating problem specific knowledge into genetic algorithms. In *[DAVI87]*.

[GRIF91] D. Griffiths and C. Whitney. The role of intelligent sofware agents in integrated communications management. *British Telecom Technology Journal*, 9(3), July 1991.

[GUID90] Project Guideline. An implementation architecture for the telecommunications management network for the CEC RACE programme. Technical report, RACE project R1003, March 1990.

[HAJE88] B. Hajek. Cooling schedules for optimal annealing. *Mathematics of Operations Research*, 13:311–329, 1988.

[HARM94] P. Harmon. The size of the commercial market in the US. *Intelligent Software Strategies*, X(1), January 1994.

[HASK90] L. Haskins. Artificial intelligence and corporate knowledge. *British Tecommunications Engineering Journal*, 9, April 1990.

[HELL91] R.J. Helleur, and N.R Milway. Network management systems: introductory overview. *British Telecommunications Engineering Journal*, 10, October 1991.

[HOLL75] J.J. Holland. *Adaptation in natural and artificial systems.* University of Michigan Press, 1975.

[HOLL92] J.J. Holland. Genetic algorithms. *Scientific American*, 267(1), 1992.

[HOWA88] E. Howard, D. Jackel, and P. Graf, H. Electronic neural networks. *AT&T Technical Journal*, 67(1), January 1988.

[ICGA85] J. Grefenstette (editor). Proceedings of the First International Conference on Genetic Algorithms and their Applications. Morgan Kaufmann, 1985.

[ICGA87] J. Grefenstette (editor). Proceedings of the Second International Conference on Genetic Algorithms and their Applications. Morgan Kaufmann, 1987.

[ICGA89] J. Shaeffer (editor). Proceedings of the Third International Conference on Genetic Algorithms and their Applications. Morgan Kaufmann, 1989.

[ICGA91] R. Belew, and L. Booker (editors). Proceedings of the Fourth International Conference on Genetic Algorithms and their Applications. Morgan Kaufmann, 1991.

[ICGA93] S. Forrest (editor). Proceedings of the Fifth International Conference on Genetic Algorithms and their Applications. Morgan Kaufmann, 1993.

[INDE93] The brain machines. *The Independent on Sunday*, 1993.

[JOHN89a] K. Johns. Managing large sofware systems. *Telesis*, 1989.

[JOHN89b] D.S. Johnson, C.R. Aragon, L.A. McGeoch, and C. Schevon. Optimization by simulated annealing: an experimental evaluation; Part 1, graph partitioning. *Operations Research*, 37(6):865–892, November 1989.

[JOHN91] D.S. Johnson, C.R. Aragon, L.A. McGeoch, and C. Schevon. Optimization by simulated annealing: an experimental evaluation; Part 2, graph coloring and number partitioning. *Operations Research*, 39(3):378–406, May 1991.

[JOHN92] D. Johnson and M. Adorf. Scheduling with neural networks: the case of Hubble space telescope. *International Journal on Computers and Operations Research, special issue on neural networks*, 1992.

[KIRK83] S. Kirkpatrick, C.D. Gelatt, and M.P. Vecchi. Optimization by simulated annealing. *Science*, 220(4598):671–680, May 1983.

[KLER88] H. Klerer. The OSI management architecture: an overview. *IEEE Spectrum*, 2(2), February 1988.

[KUMA92] V. Kumar. Algorithms for constraint satisfaction problems: a survey. *AI Magazine*, Spring, 1992.

[LAGU91] M. Laguna, J.W. Barnes and F. Glover. Tabu search methods for a single machine scheduling problem. *Journal of Intelligent Manufacturing*, 2, pages 63-74, 1991.

[LAWT92] G. Lawton. Genetic algorithms for schedule optimization. *AI Expert*, May 1992.

[LEBO91] P Lebouc and E. Stern. Distributed problem solving in broadband telecommunications network management. In *11th International Conference on Expert Systems and their Applications*, Avignon'91, 1991.

[LIEB88] J Liebowitz (editor). *Expert systems applications in telecommunications.* Wiley Series in Telecommunications. 1988.

[LIEP91] G.E. Liepins and W.D. Potter. A genetic algorithm approach to multi-fault diagnosis. In *[DAVI91b].*

[LIN73] S. Lin and B.W. Kernighan. An effective heuristic algorithm for the travelling salesman problem. *Operations Research*, 21:498–516, 1973.

[LIPP91] B. Lippolt, H. Velthuijsen, and E. Kwast. Evaluation of applying model-based diagnosis to telecommunications networks. In *11th International Conference on Expert Systems and their Applications.* Avignon'91, 1991.

[LIRO91a] Y. Lirov and B. Melaned. Expert design systems for telecommunications. *Expert Systems with Applications*, 2:219–228, 1991.

[LIRO91b] Y. Lirov and O. Yue. Expert maintenance systems in telecommunication networks. *Journal of Intelligent and Robotic Systems*, (4):303–319, 1991.

[LOES90] R. Loesener, C.A. Azmoodeh, J. Bigham, and B. Stahl. The use of advanced information processing techniques in maintenance systems for integrated broadband networks. In *Fourth Race TMN Conference*, Dublin, November 1990.

[LOGO92] M. Logothetis, and M. Shioda. " Centralised virtual path bandwidth allocation scheme for ATM networks. IEICE Trans Commun, Vol E75-B, No 10, pages 1071-1080, October 1992.

[LUND86] M. Lundy and A. Mees. Convergence of an annealing algorithm. *Mathematical Programming*, 34:111–124, 1986.

[LUSH90] E.P. Lusher. AI and communications network design. *AI Expert*, August 1990.

[MALC90] J. Malcom and T. Wooding. IKBs in network management. *Computer Communications*, November 1990.

[MALE89] M. Malek, M. Guruswamy, M. Pandya, and H.Owens. Serial and parallel simulated annealing and tabu search algorithms for the traveling salesman problem. *Annals of Operations Research*, 21,59-84, 1989.

[MAMD91] H. Mamdani and R. Smith. Advanced information processing for network management. *British Telecommunications Technology Journal*, 9(3), July 1991.

[MANN90] K. Manning and D. Spencer. Model-based network management. In *Fourth RACE TMN Conference*, Dublin, November 1990.

[MASS90] E. Masson and Y. Wang. Introduction to computation and learning in artificial neural networks. *European Journal of Operational Research*, 47:1–28, 1990.

[MAYO90] J. Mayo. The telecommunications explosion: evolution of the I.N. In *The Information Technology Revolution, third edition*, T. Forester (editor), Blackwell, 1990.

[MCCU88] N. McCulloch, W. Ainsworth, and A. Linggard. Multi-layers perceptrons applied to speech technology. *British Telecom Technology Journal*, 6(2), April 1988.

[METR53] N. Metropolis, A. Rosenbluth, M. Rosenbluth, A. Teller, and E Teller. Equation of state calculations by fast computing machines. *Journal of Chemical Physics*, 21:1087–1092, 1953.

[MORR91] J. T. Morris and B. Samadi. Neural networks in communications: admission control and switch control. In *International Conference in Communications (ICC'91)*, Denver, 1991.

[MULL92] C.Muller, E.H.Magill, and D.G.Smith. Multi-thread interface for telecommunications applications. Eighth International Conference on Software Engineering for Telecommunications Systems and Services, IEE (conference publication no 352).

[MYER90] J. Myers. The British Telecom Connectionist Project. In *The market place, neural computing; Third International Seminar*, IBL Technical Services, 1990.

[NAKA91] R. Nakano. Conventional genetic algorithm for job shop problems. In *[ICGA91].*

[NICH93] D. Nicholas and J. Yeomans. 1992 - The impact of the EC on telecommunications (a tutorial). In *The 4th IEE Conference on Telecommunications, Manchester.*, April 1993.

[OLIV87] I. M. Oliver, D. J. Smith, and J.R.C. Holland. A study of permutation crossover operators on the traveling salesman problem. In *[ICGA87].*

[PARU87] H. Van Dyke. Parunak. Why scheduling is hard (and how to do it anyway)? In *Proceedings of the 1987 Material Handling Focus.* Georgia Institute of Technology, September 1987.

[PENR89] R. Penrose. *The Emperor's new mind.* Oxford University Press, 1989.

[PERR90] E.L. Perry. Solution of time constrained scheduling problems with parallel tabu search. *Proc 1990 DARPA workshop, Innovative approaches to planning, scheduling, and control*, 231-239, 1990.

[PROS91] P. Prosser and C. Muller. A design for an intelligent problem solving agent. Technical Report, University of Strathclyde, November 1991.

[PROS94] P. Prosser, C. Muller, and C. Brind. A preliminary study of stochastic search techniques applied to vehicle routing problems. *BT report*, University of Strathclyde, February 1994.

[PSAL90] D. Psaltis, D. Brady, G. Xiang-Guang, and S. Lin. Holography in artificial neural networks. *Nature*, 343, January 1990.

[RACE90] *RACE II, workplan, background material, rationale and overview, definition of scope, and task description, RA3027-2.* 1990.

[RUDG93] W. Rudge. I'll be seeing you. *IEE Review*, November 1993.

[SCHA92] J.D. Schaffer and L.J. Eshelman. On crossover as an evolutionary viable strategy. In *[ICGA91].*

[SIMO58] A. Simon and A. Newel. Heuristic problem solving: the next advance in operations research. *Operations Research*, page 8, January 1958.

[SING94] A. Singleton. Genetic programming with C++. *Byte*, pages 171–176, February 1994.

[SINN91] N. Sinnadurai and G. Morrow. Service management systems. *British Telecommunications Engineering Journal*, 10, October 1991.

[SMIT91] R. Smith and I. Williamson. Network management for RACE. *British Telecommunications Engineering Journal*, 10, October 1991.

[SMIT90] S. F. Smith, P. S. Ow, and J. Y. Potvin. OPIS: an opportunistic factory scheduling system. *IEA/AIE 90: industrial and engineering applications of artificial intelligence and expert systems*, Proceedings of the third international conference, Charleston, South Carolina, July 15-18, 1990, vol 1.

[SOLO83] M. Solomon. *Vehicle routing with time window constraints: models and algorithms.".* PhD thesis, Department of Decision Sciences, University of Pennsylvania, 1983.

[STAR91] T. Starkweather, S. McDaniel, K. Mathias, D. Whitley, and S. Whitley. A comparison of genetic sequencing operators. In *[ICGA91].*

[SYSW91] G. Syswerda. Schedule optimization using genetic algorithms. In *[DAVI91b].*

[THAN91] S. R. Thangiah, K. E. Nygard, and P. L. Juell. Gideon: a genetic algorithm system for vehicle routing with time windows. In IEEE Computer Society Press, *CAIA-91: Proceedings of the Seventh Conference on Artificial Intelligence Applications*, 1991.

[THAN93] S. R. Thangiah, R. Vinayagamoorthy, and A. V. Gubbi. Vehicle routing with time deadlines using genetic and local algorithms. In *[ICGA93].*

[TSAN93] E. Tsang. *Foundations of constraint satisfaction.* Academic Press, 1993.

[WEIZ90] J. Weizenbaum. *The myths of artificial intelligence.* In *The Information Technology Revolution, third edition*, T. Forester (editor), Blackwell, 1990.

[WHIT89] D. Whitley, T. Starweather, and D. Fuquay. Scheduling problems and traveling salesman: the genetic edge recombination operator. In *[ICGA89].*

[WILL91] K. Willetts. Co-operative management, the key to managing customers networks. *British Telecom Engineering Journal*, 10, October 1991.

[WRIG90] R. Wright and T. Vesonder. Expert systems in telecommunications. *Expert Systems with Applications*, 1:127–136, 1990.

Annexe A: The problem generator.

Annexe A describes the software which generated the 36 problems used for the experiments. This problem generator is mainly the result of some lengthy discussions between Dr Prosser, Mr Brind and myself. Dr Prosser implemented this problem generator. The following description is taken from a previous technical report: "A preliminary study of stochastic search techniques applied to vehicle routing problems", by P.Prosser, C.Muller, and C.Brind, University of Strathclyde, February 1994.

The VRP Generator

In this section we describe the vehicle routing problem (vrp) generator. We describe the parameters to the generator, the output from the generator, and the characteristics of the problems created. Finally, the database of vrp's for this preliminary study is described.

Parameters

The vrp generator takes the following parameters

Output file: The output file name typically follows the convention C-E-J-D-T-S-N where C is the name of the coordinates file, E is the number of engineers, J is the number of jobs, D is the *bag* of durations (typically $d1$ or $d2$, and see below), T is the *bag* of time windows (typically $t0$, $t1$, or $t2$, again see below), S is the amount of specialisation in the workforce (typically $s0$, $s1$, $s2$, or $s3$, and again see below), and N is a sequence number (the number of the problem generated with these characteristics).

Coordinates file (C) A file of postal codes with their corresponding $x - y$ coordinates, where both x and y are measured in decametres. At present we have 7 data sets, namely Glasgow, G5k (a subset of the Glasgow postal codes within a 5 kilometres of a central location), G7k (as G5k but a 7k radius), Birmingham, B5k (extracted from Birmingham), B7k, and Uxbridge. When generating a problem, the $x - y$ locations of the jobs are randomly drawn from the specified coordinates file *without removal.* That is, it is possible to produce two jobs with the same postal codes and (consequently) the same $x - y$ location.

It should be noted that a problem generated from *5k (where * may be G or B) will tend to involve less travel (tend to be more *urban*) than a similar problem generated from *7k (tends to be more *rural*)[5]. Problems generated with the Uxbridge data set tend to be predominantly *rural*, involving considerable travel.

Speed This is the average speed of an engineer, in miles per hour. Typically we assume 12mph for our urban problems. This is then converted to metres per

[5]... and might even be considered to be sub-urban

minute.

Number of engineers (E) The number of engineers for the problem (typically 30, 40, or 50).

Number of jobs (J) The number of jobs in the problem (typically 200).

Bag of durations (D) A list of possible durations for jobs, measured in minutes. When a job is created a duration for that job is drawn randomly from this bag. [6] A random number is then generated (drawn from the uniform distribution) in the range 1 to n, where n is the number of elements in the bag. The nth element of the bag is then selected. For example, if we wish to generate a set of jobs such that the probability that a job has a duration of 60 minutes is 0.1 (ie. p(60) = 0.1), p(45) = 0.3, and p(30) = 0.6 we would use the bag $\{60, 45, 45, 45, 30, 30, 30, 30, 30, 30\}$.

Bag of time windows (T) A bag of temporal intervals, where a temporal interval has a start time s and an end time e. When a job is created a time window is then selected from this bag (using the same technique described above), such that the duration of the job is less than or equal to $e - s$ of the selected temporal interval. Typically a temporal interval would be (540 1020) (9 o'clock to 5 o'clock, measured in minutes from midnight, also called *all day*), (540 720) the morning, and (720 1020) the afternoon. Therefore, we may have a bag {(540 720),(540 720),(540 1020),(720 1020),(720 1020)} which will result in the probability of a job being done in the morning equal to 0.4 (p(morning) = 0.4), p(all day) = 0.2, and p(afternoon) = 0.4. [7].

Bag of specialisations (S) A bag of specialisations, where a specialisation is a percentage of the population of engineers that can do a job. When a job is

[6] A bag can be thought of as a kind of set, except elements can occur many times. The bag is then used as an *explicit* representation of a distribution.

[7] Note that with a bag {(540 1020)} all jobs may be done any time within the working day, and corresponds to no temporal constraints

created a value S is drawn from this bag (using the same technique as above). $E \times S$ engineers are then randomly chosen from the set of engineers, and marked as being capable of doing that job. For example, the bag $s_0 = \{1.0\}$ implies any job can be done by any engineer (consequently no technological constraints), $s_1 = \{0.8,0.8,0.8,0.8,0.2\}$ implies 80% of the jobs can be done by 80% of the engineers and 20% of the jobs can be done by 20% of the engineers (a weak technological constraint), and $s_3 = \{0.2,0.2,0.2,0.2,0.8\}$ implies 80% of the jobs can be done by 20% of the engineers and 20% of the jobs can be done by 80% of the engineers (a tight technological constraint).

Probability of compulsory jobs The probability that a job must be done. Typically p(compulsory) is 0.1

Normalised distances If set to true then all $x - y$ coordinates are normalised. That is, the minimum x location (x_{min}) is found from the job set, and the minimum y location is also found (y_{min}). The $x - y$ locations of all jobs are then reduced by x_{min} and y_{min}.

All jobs do-able If true then any job that is created must be feasible. A job is feasible if it is possible to travel to that job, start and complete the job within its time window, and return to the base before end of day (and all problems have been created with this flag set to true).

Generator Output

Given the outut file name *outf* (for example) the generator outputs 4 files in the following directories.

vrp/outf The actual machine readable vehicle routing problem.

gnu/outf.jobs The $x-y$ coordinates of the jobs. These can then be plotted (using gnuplot) to show graphically the distribution of the jobs.

gnu/outf.base The $x-y$ location of the base

parms/outf A summary on the problem generated. This file records the actual parameters used when generating the problem, and gives a summary analysis of the problem. This is described in more detail below.

Analysis of Problems

As noted above, the parms file for a problem (parms/outf) records the actual parameters used in generating the problem, along with an analysis of the resultant problem. A sample parms file is given below along with its corresponding graphic (the scatter of jobs and the base on the xy plane) in Figure 1.

```
Coordinates file /usr/keg/bt/vrp-prelim/data/g5k
Output files /usr/keg/bt/vrp-prelim/*/g5k-30-200-d1-tw1-s2-1.*
mph=12 n=30 m=200 p-compulsory=0.1
durations (15 30 45 60 75 90 105 120)
time windows ((540 720) (540 720) (540 1020) (720 1020) (720 1020))
specialisations (0.8 0.2)

Of 200 jobs 200 can be reached
There are 19 compulsory jobs
jobs per engineer 95.2 6.5 83.0 110.0 30 95.0
job durations 68.47 34.13 15.0 120.0 200 60.0
time-windows 277.8 111.5 180.0 480.0 200 300.0
duration over time window 0.28 0.17 0.03 0.67 200 0.25
engineers per job 14.28 8.97 6.0 24.0 200 6.0
distance from base in minutes 9.01 4.25 1.0 16.0 200 9.0
distance between jobs in minutes 13.0 6.54 0.0 31.0 19900 13.0
Average Engineer Load 1.2
coefficients 0.46 0.39 0.01 2.93 20100 0.32
Profit Coefficient = 3
Base Location = (4823 4482)
```

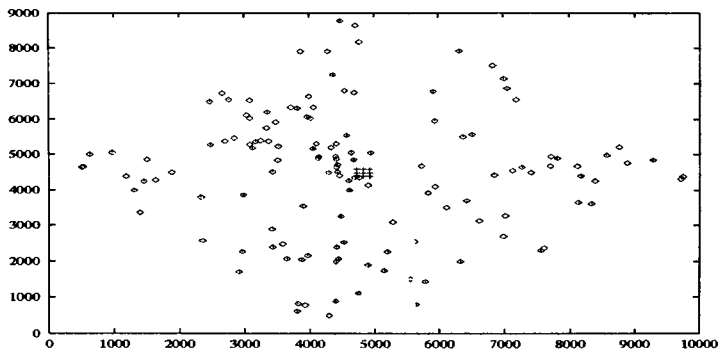


Figure A.1: g5k-30-200-d1-tw1-s2-1

The problem has 30 engineers and 200 jobs. The probability that a job is compulsory is 0.1, and engineers travel at 12 mph. Durations of jobs are in the range 15 minutes to 120 minutes, in 15 minute increments, each duration equally likely (and this bag of durations is named $d1$). The time window for a job can be in the morning, all day, or in the afternoon. The probability of a job having an *all day* time window is 0.2, and the probability of a morning time window is 0.4, the same as the probability of an afternoon time window (NOTE: this bag of time windows is named $tw1$). The bag of specialisations (the *technological* constraints) dictates that 50% of the jobs can be done by 80% of the engineers, and the remaining 50% of the jobs can be done by 20% of the engineers (and this bag of specialisations is named $s2$).

The next block of text refers to the analysis of the problem created. The figures to the right generally fall into six columns: the mean, standard deviation, minimum, maximum, sample size, median. In this case 200 jobs were created and all were feasible, and 19 of those jobs were compulsory.

jobs per engineer shows the number of jobs that each engineer is capable of doing. This can be taken as a measure of the technological constraints.

job durations shows statistics on the durations of the jobs produced. As expected, the durations of the jobs are on average about mid-way between 60 and 75 minutes.

time-windows shows statistics on the durations of time windows for jobs. In this case the average duration of time windows is 277 minutes.

duration over time window gives an indication of the tightness of the temporal constraints. For each job, the duration of that job is divided by the duration of its time window, and this value is collected. If the duration of jobs are high with respect to the duration of the time windows we get a large value,

and this indicates that temporal constraints are tight (ie. the engineers must get to the job close to the start of the time window). Low values correspond to relaxed temporal constraints (ie. engineers can arrive at a job some time after the start of a time window). Note that the tightness of the temporal constraints are controlled by the interplay between the parameters **D** (bag of durations) and **T** (bag of time windows).

engineers per job is symmetrical to the row *jobs per engineer*, allowing us a job-based perspective of the problem. As the technological constraints become tighter we will see this value fall. In this example we see that on average each job can be done by 14 engineers (out of 30, and is considered a moderately tight technological constraint).

distance from base in minutes For each job, we compute the distance from the base to that job, in minutes, given the location of the base and the job and the speed that engineers travel. For rural problems we expect this value to be larger than its urban counterpart. The distance between locations is taken as the *Manhattan* distance[8].

distance between jobs in minutes For all pairs of jobs [9] compute the travel time between jobs. For rural problems we expect this value to be larger than its urban counterpart. Again, Manhattan distance is assumed.

Average Engineer Load This is an estimate of the loading on engineers, and is computed as follows. Given **J** jobs, each of (on average) **D** duration, and **E** engineers we compute the average number of jobs an engineer is expected to do (**J/E**). Consequently the engineer will be expected to work **D.J/E** minutes in the day. The engineer must travel from the base to the first job,

[8]Manhattan distance assumes a *grid* layout, such that one travels up and down, and left and right, but not diagonally. This is a typical restriction in an urban environment, and especially so in Manhattan!

[9]If we have n jobs we compute the $n(n-1)/2$ distances between jobs.

travel between the jobs, and travel from the last job to the base. Using the calculations on travel time (from base and inter-job) and job durations we then divide the number of minutes an engineer is expected to work and travel by the number of minutes in the working day (480).

If this value is large (ie greater than 0.9) we anticipate that the problem is under-resourced, and it is unlikely that all jobs will be done. A good solution will then (typically) attempt to minimise jobs not done. When this value is low (ie. less than 0.85) we expect that the problem is over-resourced, and all jobs will be done. Consequently a good solution will be one that minimises travel (since all jobs will probably be done, this is the only scope for differentiating solutions).

coefficients A ratio based on the travel associated with a job, and the duration of that job. For each job we measure the distance that could be traveled in order to perform that job. That is, for job job_j an engineer may have to travel from job job_i to job job_j and take travel time $t_{i,j}$, perform job_j with duration d_j, and then return to the base taking travel time $t_{j,0}$. The coefficient $C_{i,j}$ for this *triangle* of travel and work (from job_i to job_j to the base, job_0) is calculated as $C_{i,j} = \frac{t_{i,j}+t_{j,0}}{d_j}$.

This value is computed for all possible pairs of jobs job_i and job_j, where $i \neq j$, and $0 \leq i \leq J$[10]

Problems with high values for $C_{i,j}$ tend to have considerable amount of travel, or jobs with relatively low durations. Symmetrically, problems with low values of $C_{i,j}$ tend to have low travel to jobs of relatively high duration. Therefore, a rural problem tends to have high $C_{i,j}$ with respect to its urban counterpart, and problems with short duration jobs have high $C_{i,j}$ compared to similar problems with jobs of large durations.

[10]That is we also consider the tour from the base (job_0) to job_j, then returning to the base.

Profit Coefficient The profit coefficient is used by the cost function employed by the search process. The profit coefficient C is taken to be the maximum value of $C_{i,j}$ (rounded up to the nearest integer).

In evaluating a solution we take into consideration the sum of the durations of the jobs that have not been done ($\bar{D}$), and the sum of the travel time for all engineers (T). The cost of a solution is then $C\bar{D} + T$. The coefficient C guarantees that the term $C\bar{D}$ is always greater than the travel associated with doing the jobs that have not been done. An alternative way of looking at this is, we guarantee that the search process cannot produce a lower cost solution by reducing travel by not doing jobs, consequently there is always a motive to do more work.

Base Location This is the $x - y$ location of the base and is generated such that it corresponds approximately to the centre of gravity of the location of the jobs.

Therefore, it should be apparent that we can produce vrp's that are under-resourced and over-resourced. We can produce an under-resourced vrp by decreasing the number of engineers, or by increasing the number of jobs or the durations of the jobs, or by increasing the travel between jobs. Furthermore, we have a (coarse) measure of this, namely *load*. Generally, we vary load by altering the number of engineers and the durations of jobs.

Similarly, we can vary the tightness of the temporal and technological constraints. We can increase the tightness of the temporal constraints by making the time windows smaller, or by increasing the durations of jobs (but this has the side-effect of increasing load). We can also increase the tightness of the technological constraints (by limiting who can do a job).

Bringing this together, there appears to be (at least) 4 extreme scenarios. First, we may have vrp's that are under-resourced but with no temporal or technological

constraints. Then, we can have under-resourced vrp's with tight temporal and technological constraints. There are then over-resourced problems with no temporal or technological constraints, and over-resourced problems with tight temporal and technological constraints. Therefore, we hope that we can investigate the role of *load* independently of constraint tightness (and vice versa). Further, we have the ability to generate a range of problems within those extremes.

VRP Database

As part of the preliminary study, 216 vrp's have been produced, with the following characteristics.

location All vrp's have been generating using the g5k coordinates file. That is the Glasgow postcodes in a 5k radius of G1. This produces *urban* problems, and all problems tend to have the same distances between jobs, and between jobs and the base.

Number of Engineers The number of engineers is 30, 40, or 50.

Number of Jobs The number of jobs is held constant at 200.

Durations Durations of jobs are drawn randomly from the bags d1 or d2, where

d1 is $\{15, 30, 45, 60, 75, 90, 105, 120\}$.

d2 is $\{15, 15, 15, 30, 30, 30, 45, 45, 60, 60, 120, 180, 240, 300\}$.

Time Windows The temporal constraints, either t0, t1, or t2

t0 all jobs have a time window running from 9 to 5 (all day)

t1 probability of morning = probability of afternoon = 0.4 and probability of all day = 0.2

t2 probability of morning = probability of afternoon = 0.45 and probability of all day is approximately 0.1

Specialisations Specialisation (the technological constraints), either s0, s1, s2, or s3

s0 all jobs can be done by any engineer

s1 80% of jobs can be done by 80% of the engineers, and 20% of the jobs can be done by 20% of the engineers

s2 50% of the jobs can be done 80% of the engineers, and 50% of the jobs can be done by 20% of the engineers

s3 80% of the jobs can be done by 20% of the engineers, and 20% of the jobs can be done by 80% of the engineers

n A sequence number. Typically 3 problems are generated at each parameter setting

Problems have the following broad characteristics. As the number of engineers increases the load per engineer falls, and the problem moves from being under-resourced to over-resourced. Problems with durations d1 will tend to be less heavily loaded than problems with durations d2. Problems with time windows t0 have no temporal constraints, and problems with t3 have the tightest temporal constraints. Problems with specialisation s0 have no technological constraints and problems with s3 have the tightest technological constraints

At present the following set of problems has been generated. For g5k (urban), number of engineers 30, 40, or 50, all possible combinations of durations (d1 or d2), time windows (tw0, tw1, tw2), and specialisations (s0, s1, s2, s3), 3 problems at each setting (in total $3 \times 2 \times 3 \times 4 \times 3 = 216$ problems).

- Problems g5k-50-* will be over-resourced compared to g5k-40-*, and g5k-30-* is under-resourced.

- Problems *-d2-* will tend to have a greater spread of job durations than problems *-d1-*, and *-d2-* will tend to put a higher loading on engineers
- Problems *-tw0-* have no temporal constraints, and problems *-tw2-* is the most temporal constrained.
- Problems *-s0-* have no technological constraints, and problems *-s3-* have the most technological constraints.

Annexe B: Raw results.

The following tables give the raw experimental results. Each line corresponds to the five applications of an algorithm to a specific problem. A table entry is a triple: cost, travel and work not done.

Problems	1			2			3			4			5		
30-0-0-1	973932	1932	1620	982916	1916	1635	1000927	1927	1665	991944	1944	1650	964899	1899	1605
30-0-0-2	793969	1969	1320	757947	1947	1260	757970	1970	1260	766953	1953	1275	766946	1946	1275
30-0-0-3	622980	1980	1035	604966	1966	1005	622956	1956	1035	631997	1997	1050	631978	1978	1050
30-0-3-1	758017	2017	1260	767052	2052	1275	767057	2057	1275	767043	2043	1275	767020	2020	1275
30-0-3-2	820993	1993	1365	794034	2034	1320	776019	2019	1290	812078	2078	1350	811989	1989	1350
30-0-3-3	1108906	1906	1845	1018777	1777	1695	1099945	1945	1830	1063889	1889	1770	1099981	1981	1830
30-2-0-1	910940	1940	1515	883968	1968	1470	919981	1981	1530	874934	1934	1455	902031	2031	1500
30-2-0-2	766918	1918	1275	758028	2028	1260	776103	2103	1290	776092	2092	1290	758071	2071	1260
30-2-0-3	1504884	1884	2505	1487037	2037	2475	1504834	1834	2505	1495901	1901	2490	1504811	1811	2505
30-2-3-1	1325044	2044	2205	1316123	2123	2190	1370188	2188	2280	1334063	2063	2220	1352060	2060	2250
30-2-3-2	1135987	1987	1890	1153943	1943	1920	1145087	2087	1905	1163168	2168	1935	1145031	2031	1905
30-2-3-3	884097	2097	1470	902048	2048	1500	866125	2125	1440	884132	2132	1470	893102	2102	1485
40-0-0-1	2290	2290	0	2235	2235	0	2269	2269	0	2229	2229	0	2278	2278	0
40-0-0-2	2226	2226	0	2247	2247	0	2185	2185	0	2235	2235	0	2287	2287	0
40-0-0-3	2180	2180	0	2211	2211	0	2190	2190	0	2111	2111	0	2173	2173	0
40-0-3-1	2302	2302	0	2235	2235	0	2335	2335	0	2324	2324	0	2296	2296	0
40-0-3-2	2154	2154	0	2211	2211	0	2229	2229	0	2160	2160	0	2209	2209	0
40-0-3-3	2385	2385	0	2385	2385	0	2441	2441	0	2434	2434	0	2380	2380	0
40-2-0-1	461275	2275	765	461334	2334	765	434268	2268	720	461119	2119	765	452280	2280	750
40-2-0-2	65293	2293	105	56199	2199	90	74199	2199	120	65213	2213	105	56313	2313	90
40-2-0-3	47360	2360	75	47465	2465	75	29442	2442	45	56421	2421	90	56398	2398	90
40-2-3-1	47643	2643	75	11547	2547	15	2510	2510	0	2594	2594	0	2715	2715	0
40-2-3-2	2351	2351	0	2309	2309	0	2423	2423	0	2267	2267	0	2275	2275	0
40-2-3-3	191412	2412	315	182435	2435	300	200383	2383	330	164358	2358	270	182395	2395	300
50-0-0-1	2260	2260	0	2312	2312	0	2332	2332	0	2310	2310	0	2273	2273	0
50-0-0-2	2242	2242	0	2249	2249	0	2231	2231	0	2194	2194	0	2249	2249	0
50-0-0-3	2223	2223	0	2242	2242	0	2181	2181	0	2217	2217	0	2224	2224	0
50-0-3-1	2293	2293	0	2274	2274	0	2234	2234	0	2322	2322	0	2262	2262	0
50-0-3-2	2340	2340	0	2288	2288	0	2299	2299	0	2307	2307	0	2333	2333	0
50-0-3-3	2292	2292	0	2305	2305	0	2359	2359	0	2326	2326	0	2307	2307	0
50-2-0-1	2228	2228	0	2231	2231	0	2208	2208	0	2232	2232	0	2228	2228	0
50-2-0-2	2083	2083	0	2108	2108	0	2106	2106	0	2104	2104	0	2104	2104	0
50-2-0-3	2114	2114	0	2129	2129	0	2070	2070	0	2104	2104	0	2120	2120	0
50-2-3-1	2208	2208	0	2200	2200	0	2173	2173	0	2179	2179	0	2185	2185	0
50-2-3-2	2364	2364	0	2389	2389	0	2393	2393	0	2375	2375	0	2429	2429	0
50-2-3-3	2409	2409	0	2417	2417	0	2440	2440	0	2414	2414	0	2401	2401	0

Table B.1: PMX, raw results.

Problems	1			2			3			4			5		
30-0-0-1	721464	1464	1200	703428	1428	1170	712454	1454	1185	667413	1413	1110	649364	1364	1080
30-0-0-2	469433	1433	780	469409	1409	780	424387	1387	705	523536	1536	870	451444	1444	750
30-0-0-3	253363	1363	420	298448	1448	495	361551	1551	600	271422	1422	450	280387	1387	465
30-0-3-1	514624	1624	855	505629	1629	840	514639	1639	855	541647	1647	900	568708	1708	945
30-0-3-2	586715	1715	975	640774	1774	1065	568615	1615	945	541613	1613	900	586684	1684	975
30-0-3-3	838470	1470	1395	901611	1611	1500	829493	1493	1380	838542	1542	1395	838531	1531	1395
30-2-0-1	766816	1816	1275	748745	1745	1245	775742	1742	1290	820869	1869	1365	820862	1862	1365
30-2-0-2	757938	1938	1260	694747	1747	1155	685854	1854	1140	649783	1783	1080	712883	1883	1185
30-2-0-3	1432638	1638	2385	1396595	1595	2325	1423677	1677	2370	1423701	1701	2370	1432692	1692	2385
30-2-3-1	1162929	1929	1935	1180857	1857	1965	1334049	2049	2220	1226018	2018	2040	1162869	1869	1935
30-2-3-2	1054925	1925	1755	1018919	1919	1695	1046002	2002	1740	1072997	1997	1785	1082039	2039	1800
30-2-3-3	784923	1923	1305	730820	1820	1215	829981	1981	1380	784948	1948	1305	775798	1798	1290
40-0-0-1	1399	1399	0	1346	1346	0	1348	1348	0	1403	1403	0	1343	1343	0
40-0-0-2	1232	1232	0	1342	1342	0	1414	1414	0	1298	1298	0	1340	1340	0
40-0-0-3	1360	1360	0	1207	1207	0	1329	1329	0	1333	1333	0	1268	1268	0
40-0-3-1	1528	1528	0	1465	1465	0	1529	1529	0	1409	1409	0	1476	1476	0
40-0-3-2	1446	1446	0	1509	1509	0	1526	1526	0	1426	1426	0	1477	1477	0
40-0-3-3	1501	1501	0	1505	1505	0	1563	1563	0	1630	1630	0	1448	1448	0
40-2-0-1	442986	1986	735	407033	2033	675	415981	1981	690	389029	2029	645	433993	1993	720
40-2-0-2	29035	2035	45	65210	2210	105	47023	2023	75	74176	2176	120	56165	2165	90
40-2-0-3	56302	2302	90	2166	2166	0	2046	2046	0	2171	2171	0	2134	2134	0
40-2-3-1	2319	2319	0	2427	2427	0	2464	2464	0	2425	2425	0	2630	2630	0
40-2-3-2	2064	2064	0	1943	1943	0	1982	1982	0	1962	1962	0	2466	2466	0
40-2-3-3	164285	2285	270	182349	2349	300	164222	2222	270	20032	2032	30	182305	2305	300
50-0-0-1	1418	1418	0	1393	1393	0	1329	1329	0	1452	1452	0	1485	1485	0
50-0-0-2	1246	1246	0	1363	1363	0	1401	1401	0	1349	1349	0	1268	1268	0
50-0-0-3	1251	1251	0	1288	1288	0	1286	1286	0	1473	1473	0	1287	1287	0
50-0-3-1	1511	1511	0	1459	1459	0	1564	1564	0	1584	1584	0	1493	1493	0
50-0-3-2	1433	1433	0	1570	1570	0	1444	1444	0	1642	1642	0	1517	1517	0
50-0-3-3	1497	1497	0	1527	1527	0	1505	1505	0	1547	1547	0	1576	1576	0
50-2-0-1	1641	1641	0	1659	1659	0	1657	1657	0	1686	1686	0	1778	1778	0
50-2-0-2	1449	1449	0	1523	1523	0	1488	1488	0	1424	1424	0	1585	1585	0
50-2-0-3	1554	1554	0	1579	1579	0	1508	1508	0	1530	1530	0	1578	1578	0
50-2-3-1	1739	1739	0	1933	1933	0	1757	1757	0	1972	1972	0	1818	1818	0
50-2-3-2	2146	2146	0	2128	2128	0	2158	2158	0	2085	2085	0	2043	2043	0
50-2-3-3	2030	2030	0	1933	1933	0	1944	1944	0	1983	1983	0	1860	1860	0

Table B.2: Direct3, raw results.

Problems	1			2			3			4			5		
30-0-0-1	667377	1377	1110	658409	1409	1095	694423	1423	1155	685402	1402	1140	595342	1342	990
30-0-0-2	442412	1412	735	397279	1279	660	478487	1487	795	379294	1294	630	433394	1394	720
30-0-0-3	289403	1403	480	280417	1417	465	280415	1415	465	334530	1530	555	280404	1404	465
30-0-3-1	577730	1730	960	505628	1628	840	523659	1659	870	478584	1584	795	496561	1561	825
30-0-3-2	505577	1577	840	514451	1451	855	496522	1522	825	541624	1624	900	595656	1656	990
30-0-3-3	802444	1444	1335	811540	1540	1350	847469	1469	1410	820502	1502	1365	838497	1497	1395
30-2-0-1	631555	1555	1050	703620	1620	1170	739712	1712	1230	766725	1725	1275	676614	1614	1125
30-2-0-2	685875	1875	1140	622692	1692	1035	685808	1808	1140	586746	1746	975	676731	1731	1125
30-2-0-3	1432546	1546	2385	1405559	1559	2340	1432548	1548	2385	1405435	1435	2340	1441576	1576	2400
30-2-3-1	1171947	1947	1950	1189952	1952	1980	1207981	1981	2010	1253031	2031	2085	1306986	1986	2175
30-2-3-2	1018995	1995	1695	1018924	1924	1695	1009879	1879	1680	946844	1844	1575	973836	1836	1620
30-2-3-3	712875	1875	1185	820799	1799	1365	820922	1922	1365	766816	1816	1275	803040	2040	1335
40-0-0-1	1354	1354	0	1330	1330	0	1388	1388	0	1271	1271	0	1326	1326	0
40-0-0-2	1354	1354	0	1381	1381	0	1278	1278	0	1271	1271	0	1392	1392	0
40-0-0-3	1284	1284	0	1309	1309	0	1372	1372	0	1276	1276	0	1295	1295	0
40-0-3-1	1630	1630	0	1582	1582	0	1629	1629	0	1478	1478	0	1456	1456	0
40-0-3-2	1442	1442	0	1394	1394	0	1448	1448	0	1505	1505	0	1513	1513	0
40-0-3-3	1556	1556	0	1490	1490	0	1646	1646	0	1589	1589	0	1533	1533	0
40-2-0-1	406976	1976	675	370999	1999	615	379890	1890	630	397991	1991	660	379920	1920	630
40-2-0-2	38097	2097	60	73853	1853	120	2083	2083	0	1874	1874	0	2010	2010	0
40-2-0-3	1980	1980	0	56002	2002	90	2057	2057	0	2103	2103	0	2165	2165	0
40-2-3-1	2171	2171	0	2163	2163	0	2465	2465	0	2180	2180	0	2387	2387	0
40-2-3-2	1961	1961	0	2014	2014	0	2022	2022	0	1984	1984	0	1964	1964	0
40-2-3-3	182145	2145	300	110178	2178	180	83158	2158	135	101165	2165	165	128225	2225	210
50-0-0-1	1335	1335	0	1420	1420	0	1277	1277	0	1387	1387	0	1379	1379	0
50-0-0-2	1398	1398	0	1435	1435	0	1472	1472	0	1274	1274	0	1434	1434	0
50-0-0-3	1367	1367	0	1305	1305	0	1308	1308	0	1409	1409	0	1215	1215	0
50-0-3-1	1566	1566	0	1684	1684	0	1500	1500	0	1561	1561	0	1564	1564	0
50-0-3-2	1547	1547	0	1579	1579	0	1576	1576	0	1490	1490	0	1534	1534	0
50-0-3-3	1632	1632	0	1582	1582	0	1565	1565	0	1659	1659	0	1614	1614	0
50-2-0-1	1636	1636	0	1551	1551	0	1776	1776	0	1744	1744	0	1741	1741	0
50-2-0-2	1648	1648	0	1634	1634	0	1491	1491	0	1560	1560	0	1470	1470	0
50-2-0-3	1540	1540	0	1569	1569	0	1513	1513	0	1586	1586	0	1565	1565	0
50-2-3-1	1893	1893	0	1988	1988	0	1768	1768	0	1815	1815	0	1875	1875	0
50-2-3-2	2171	2171	0	2100	2100	0	2212	2212	0	2080	2080	0	1968	1968	0
50-2-3-3	2018	2018	0	2008	2008	0	1907	1907	0	1937	1937	0	2070	2070	0

Table B.3: Direct3-s, raw results.

Problems	1			2			3			4			5		
30-0-0-1	631329	1329	1050	568245	1245	945	595346	1346	990	559239	1239	930	586273	1273	975
30-0-0-2	370299	1299	615	433353	1353	720	433373	1373	720	352207	1207	585	334210	1210	555
30-0-0-3	217317	1317	360	262314	1314	435	208312	1312	345	289387	1387	480	280389	1389	465
30-0-3-1	433407	1407	720	406502	1502	675	442513	1513	735	487554	1554	810	406434	1434	675
30-0-3-2	487494	1494	810	469494	1494	780	532540	1540	885	478514	1514	795	469503	1503	780
30-0-3-3	775406	1406	1290	847559	1559	1410	775368	1368	1290	802476	1476	1335	766379	1379	1275
30-2-0-1	640517	1517	1065	676657	1657	1125	631549	1549	1050	694592	1592	1155	604487	1487	1005
30-2-0-2	658573	1573	1095	595772	1772	990	586601	1601	975	586639	1639	975	613546	1546	1020
30-2-0-3	1432574	1574	2385	1378385	1385	2295	1387526	1526	2310	1432473	1473	2385	1414487	1487	2355
30-2-3-1	1198919	1919	1995	1207905	1905	2010	1162694	1694	1935	1189778	1778	1980	1144785	1785	1905
30-2-3-2	892736	1736	1485	955827	1827	1590	919724	1724	1530	928867	1867	1545	901760	1760	1500
30-2-3-3	757795	1795	1260	784815	1815	1305	766840	1840	1275	739782	1782	1230	775952	1952	1290
40-0-0-1	1354	1354	0	1349	1349	0	1354	1354	0	1314	1314	0	1304	1304	0
40-0-0-2	1339	1339	0	1413	1413	0	1338	1338	0	1253	1253	0	1348	1348	0
40-0-0-3	1299	1299	0	1280	1280	0	1304	1304	0	1300	1300	0	1427	1427	0
40-0-3-1	1652	1652	0	1492	1492	0	1681	1681	0	1518	1518	0	1571	1571	0
40-0-3-2	1494	1494	0	1498	1498	0	1624	1624	0	1517	1517	0	1502	1502	0
40-0-3-3	1623	1623	0	1631	1631	0	1664	1664	0	1597	1597	0	1688	1688	0
40-2-0-1	415982	1982	690	424843	1843	705	352858	1858	585	406869	1869	675	361881	1881	600
40-2-0-2	1798	1798	0	1719	1719	0	1841	1841	0	19978	1978	30	1846	1846	0
40-2-0-3	2054	2054	0	2025	2025	0	1996	1996	0	1895	1895	0	1954	1954	0
40-2-3-1	2187	2187	0	2124	2124	0	2215	2215	0	2115	2115	0	2241	2241	0
40-2-3-2	1967	1967	0	1996	1996	0	1863	1863	0	1965	1965	0	1981	1981	0
40-2-3-3	101160	2160	165	128290	2290	210	83199	2199	135	164209	2209	270	65187	2187	105
50-0-0-1	1381	1381	0	1384	1384	0	1358	1358	0	1320	1320	0	1428	1428	0
50-0-0-2	1353	1353	0	1467	1467	0	1448	1448	0	1412	1412	0	1433	1433	0
50-0-0-3	1270	1270	0	1349	1349	0	1289	1289	0	1288	1288	0	1205	1205	0
50-0-3-1	1679	1679	0	1601	1601	0	1640	1640	0	1599	1599	0	1607	1607	0
50-0-3-2	1770	1770	0	1521	1521	0	1726	1726	0	1612	1612	0	1645	1645	0
50-0-3-3	1576	1576	0	1550	1550	0	1645	1645	0	1718	1718	0	1676	1676	0
50-2-0-1	1774	1774	0	1732	1732	0	1798	1798	0	1821	1821	0	1756	1756	0
50-2-0-2	1547	1547	0	1606	1606	0	1559	1559	0	1528	1528	0	1562	1562	0
50-2-0-3	1608	1608	0	1489	1489	0	1553	1553	0	1568	1568	0	1690	1690	0
50-2-3-1	1872	1872	0	2023	2023	0	1932	1932	0	1797	1797	0	1835	1835	0
50-2-3-2	2119	2119	0	2054	2054	0	2022	2022	0	2168	2168	0	1884	1884	0
50-2-3-3	2119	2119	0	2015	2015	0	2052	2052	0	2123	2123	0	1983	1983	0

Table B.4: Direct4-s, raw results.

Problems	1			2			3			4			5		
30-0-0-1	487160	1160	810	586237	1237	975	514177	1177	855	514154	1154	855	532198	1198	885
30-0-0-2	298185	1185	495	307197	1197	510	361280	1280	600	271144	1144	450	361284	1284	600
30-0-0-3	181246	1246	300	154176	1176	255	181229	1229	300	190272	1272	315	172233	1233	285
30-0-3-1	388419	1419	645	388473	1473	645	370407	1407	615	352395	1395	585	370415	1415	615
30-0-3-2	478476	1476	795	469443	1443	780	424441	1441	705	451424	1424	750	433467	1467	720
30-0-3-3	757378	1378	1260	703291	1291	1170	694325	1325	1155	685299	1299	1140	721377	1377	1200
30-2-0-1	541409	1409	900	622564	1564	1035	586471	1471	975	586454	1454	975	577468	1468	960
30-2-0-2	523588	1588	870	559661	1661	930	532493	1493	885	604590	1590	1005	550489	1489	915
30-2-0-3	1369318	1318	2280	1378382	1382	2295	1360431	1431	2265	1387338	1338	2310	1405532	1532	2340
30-2-3-1	1162664	1664	1935	1108762	1762	1845	1135647	1647	1890	1108723	1723	1845	1099775	1775	1830
30-2-3-2	883660	1660	1470	847737	1737	1410	793634	1634	1320	883695	1695	1470	847703	1703	1410
30-2-3-3	757747	1747	1260	739684	1684	1230	784954	1954	1305	757684	1684	1260	712641	1641	1185
40-0-0-1	1221	1221	0	1257	1257	0	1235	1235	0	1337	1337	0	1196	1196	0
40-0-0-2	1217	1217	0	1298	1298	0	1262	1262	0	1284	1284	0	1221	1221	0
40-0-0-3	1254	1254	0	1220	1220	0	1248	1248	0	1147	1147	0	1209	1209	0
40-0-3-1	1503	1503	0	1463	1463	0	1396	1396	0	1429	1429	0	1463	1463	0
40-0-3-2	1368	1368	0	1436	1436	0	1379	1379	0	1398	1398	0	1393	1393	0
40-0-3-3	1559	1559	0	1482	1482	0	1484	1484	0	1473	1473	0	1562	1562	0
40-2-0-1	398060	2060	660	361888	1888	600	379838	1838	630	370754	1754	615	343783	1783	570
40-2-0-2	1713	1713	0	1675	1675	0	1850	1850	0	1827	1827	0	1686	1686	0
40-2-0-3	1702	1702	0	1785	1785	0	1718	1718	0	1631	1631	0	1749	1749	0
40-2-3-1	1950	1950	0	1950	1950	0	1828	1828	0	2116	2116	0	1960	1960	0
40-2-3-2	1821	1821	0	1780	1780	0	1936	1936	0	1852	1852	0	1805	1805	0
40-2-3-3	64907	1907	105	38053	2053	60	19988	1988	30	56020	2020	90	55943	1943	90
50-0-0-1	1287	1287	0	1209	1209	0	1308	1308	0	1307	1307	0	1273	1273	0
50-0-0-2	1206	1206	0	1232	1232	0	1235	1235	0	1380	1380	0	1211	1211	0
50-0-0-3	1105	1105	0	1131	1131	0	1361	1361	0	1216	1216	0	1239	1239	0
50-0-3-1	1453	1453	0	1466	1466	0	1521	1521	0	1593	1593	0	1533	1533	0
50-0-3-2	1482	1482	0	1501	1501	0	1533	1533	0	1468	1468	0	1612	1612	0
50-0-3-3	1480	1480	0	1490	1490	0	1475	1475	0	1472	1472	0	1469	1469	0
50-2-0-1	1599	1599	0	1756	1756	0	1582	1582	0	1618	1618	0	1588	1588	0
50-2-0-2	1494	1494	0	1552	1552	0	1500	1500	0	1406	1406	0	1487	1487	0
50-2-0-3	1434	1434	0	1542	1542	0	1496	1496	0	1492	1492	0	1529	1529	0
50-2-3-1	1787	1787	0	1675	1675	0	1790	1790	0	1823	1823	0	1783	1783	0
50-2-3-2	1924	1924	0	1989	1989	0	1908	1908	0	2080	2080	0	1927	1927	0
50-2-3-3	1844	1844	0	1875	1875	0	1899	1899	0	1873	1873	0	1920	1920	0

Table B.5: Direct4-s:200, raw results.

Problems	1			2			3			4			5		
30-0-0-1	559220	1220	930	586290	1290	975	568272	1272	945	559205	1205	930	496128	1128	825
30-0-0-2	316162	1162	525	361232	1232	600	361250	1250	600	298187	1187	495	289118	1118	480
30-0-0-3	217296	1296	360	190290	1290	315	199241	1241	330	172257	1257	285	154200	1200	255
30-0-3-1	316292	1292	525	352397	1397	585	316313	1313	525	334316	1316	555	307305	1305	510
30-0-3-2	334330	1330	555	343321	1321	570	379382	1382	630	361338	1338	600	352323	1323	585
30-0-3-3	658284	1284	1095	658246	1246	1095	658242	1242	1095	676281	1281	1125	604183	1183	1005
30-2-0-1	658608	1608	1095	640470	1470	1065	586404	1404	975	631508	1508	1050	694567	1567	1155
30-2-0-2	622635	1635	1035	568601	1601	945	541595	1595	900	604600	1600	1005	586721	1721	975
30-2-0-3	1396614	1614	2325	1405672	1672	2340	1378629	1629	2295	1396414	1414	2325	1405547	1547	2340
30-2-3-1	1072625	1625	1785	1072594	1594	1785	1099527	1527	1830	1090633	1633	1815	1081680	1680	1800
30-2-3-2	811610	1610	1350	811644	1644	1350	838625	1625	1395	802576	1576	1335	757582	1582	1260
30-2-3-3	658604	1604	1095	685621	1621	1140	631550	1550	1050	631605	1605	1050	667582	1582	1110
40-0-0-1	2214	2214	0	2107	2107	0	2220	2220	0	2229	2229	0	2238	2238	0
40-0-0-2	2182	2182	0	2226	2226	0	2225	2225	0	2243	2243	0	2209	2209	0
40-0-0-3	2155	2155	0	2158	2158	0	2177	2177	0	2143	2143	0	2153	2153	0
40-0-3-1	1445	1445	0	1410	1410	0	1361	1361	0	1388	1388	0	1430	1430	0
40-0-3-2	1310	1310	0	1423	1423	0	1318	1318	0	1298	1298	0	1343	1343	0
40-0-3-3	1476	1476	0	1520	1520	0	1479	1479	0	1494	1494	0	1506	1506	0
40-2-0-1	343767	1767	570	352762	1762	585	389203	2203	645	343699	1699	570	334765	1765	555
40-2-0-2	1835	1835	0	1899	1899	0	1782	1782	0	1850	1850	0	1843	1843	0
40-2-0-3	1730	1730	0	1693	1693	0	1784	1784	0	1803	1803	0	1588	1588	0
40-2-3-1	1797	1797	0	1895	1895	0	1870	1870	0	1866	1866	0	1872	1872	0
40-2-3-2	1686	1686	0	1745	1745	0	1663	1663	0	1714	1714	0	1732	1732	0
40-2-3-3	1893	1893	0	1905	1905	0	11020	2020	15	1823	1823	0	28973	1973	45
50-0-0-1	2301	2301	0	2275	2275	0	2293	2293	0	2224	2224	0	2291	2291	0
50-0-0-2	2169	2169	0	2190	2190	0	2216	2216	0	2155	2155	0	2219	2219	0
50-0-0-3	2153	2153	0	2197	2197	0	2222	2222	0	2148	2148	0	2197	2197	0
50-0-3-1	1411	1411	0	1462	1462	0	1500	1500	0	1497	1497	0	1458	1458	0
50-0-3-2	1381	1381	0	1459	1459	0	1412	1412	0	1533	1533	0	1563	1563	0
50-0-3-3	1349	1349	0	1431	1431	0	1419	1419	0	1579	1579	0	1483	1483	0
50-2-0-1	2115	2115	0	2155	2155	0	2190	2190	0	2193	2193	0	2172	2172	0
50-2-0-2	2040	2040	0	2038	2038	0	2068	2068	0	2033	2033	0	2068	2068	0
50-2-0-3	2069	2069	0	2053	2053	0	2098	2098	0	2068	2068	0	2087	2087	0
50-2-3-1	1557	1557	0	1559	1559	0	1672	1672	0	1625	1625	0	1799	1799	0
50-2-3-2	1910	1910	0	1808	1808	0	1933	1933	0	1817	1817	0	1916	1916	0
50-2-3-3	1863	1863	0	1801	1801	0	1863	1863	0	1806	1806	0	1846	1846	0

Table B.6: Direct4-s:400, raw results.

Problems	1			2			3			4			5		
30-0-0-1	541201	1201	900	532151	1151	885	496160	1160	825	550124	1184	915	559203	1203	930
30-0-0-2	325252	1252	540	271149	1149	450	289106	1106	480	289183	1183	480	370230	1230	615
30-0-0-3	154211	1211	255	154157	1157	255	217276	1276	360	199267	1267	330	244293	1293	405
30-0-3-1	271292	1292	450	307310	1310	510	298287	1287	495	298275	1275	495	334372	1372	555
30-0-3-2	343322	1322	570	397358	1358	660	424392	1392	705	379313	1313	630	352349	1349	585
30-0-3-3	694348	1348	1155	685287	1287	1140	676249	1249	1125	712286	1286	1185	685280	1280	1140
30-2-0-1	631471	1471	1050	640552	1552	1065	649528	1528	1080	667526	1526	1110	640583	1583	1065
30-2-0-2	604770	1770	1005	622682	1682	1035	559552	1552	930	604584	1584	1005	496404	1404	825
30-2-0-3	1405457	1457	2340	1378471	1471	2295	1387461	1461	2310	1378531	1531	2295	1387458	1458	2310
30-2-3-1	1045733	1733	1740	1126663	1663	1875	1090660	1660	1815	1108641	1641	1845	1072643	1643	1785
30-2-3-2	802680	1680	1335	802598	1598	1335	784617	1617	1305	802653	1653	1335	820679	1679	1365
30-2-3-3	640587	1587	1065	703575	1575	1170	676641	1641	1125	712679	1679	1185	721635	1635	1200
40-0-0-1	1233	1233	0	1247	1247	0	1204	1204	0	1315	1315	0	1202	1202	0
40-0-0-2	1238	1238	0	1238	1238	0	1242	1242	0	1151	1151	0	1128	1128	0
40-0-0-3	1226	1226	0	1148	1148	0	1225	1225	0	1220	1220	0	1242	1242	0
40-0-3-1	1477	1477	0	1420	1420	0	1485	1485	0	1362	1362	0	1337	1337	0
40-0-3-2	1309	1309	0	1391	1391	0	1323	1323	0	1324	1324	0	1302	1302	0
40-0-3-3	1425	1425	0	1479	1479	0	1490	1490	0	1439	1439	0	1458	1458	0
40-2-0-1	343846	1846	570	335009	2009	555	307720	1720	510	379989	1989	630	361846	1846	600
40-2-0-2	1824	1824	0	1836	1836	0	1793	1793	0	1745	1745	0	1926	1926	0
40-2-0-3	1736	1736	0	1689	1689	0	1633	1633	0	1764	1764	0	1875	1875	0
40-2-3-1	1897	1897	0	1824	1824	0	1788	1788	0	1899	1899	0	1821	1821	0
40-2-3-2	1695	1695	0	1698	1698	0	1623	1623	0	1765	1765	0	1677	1677	0
40-2-3-3	10960	1960	15	1884	1884	0	19974	1974	30	55999	1999	90	46860	1860	75
50-0-0-1	1321	1321	0	1226	1226	0	1332	1332	0	1234	1234	0	1336	1336	0
50-0-0-2	1325	1325	0	1183	1183	0	1269	1269	0	1242	1242	0	242	1242	0
50-0-0-3	1187	1187	0	1234	1234	0	1172	1172	0	1138	1138	0	1181	1181	0
50-0-3-1	1435	1435	0	1405	1405	0	1373	1373	0	1533	1533	0	1489	1489	0
50-0-3-2	1461	1461	0	1369	1369	0	1348	1348	0	1462	1462	0	1461	1461	0
50-0-3-3	1479	1479	0	1410	1410	0	1391	1391	0	1510	1510	0	1426	1426	0
50-2-0-1	1688	1688	0	1593	1593	0	1575	1575	0	1510	1510	0	1582	1582	0
50-2-0-2	1503	1503	0	1492	1492	0	1477	1477	0	1478	1478	0	1445	1445	0
50-2-0-3	1444	1444	0	1529	1529	0	1384	1384	0	1477	1477	0	1437	1437	0
50-2-3-1	1666	1666	0	1665	1665	0	1797	1797	0	1591	1591	0	1782	1782	0
50-2-3-2	1790	1790	0	1881	1881	0	1883	1883	0	1874	1874	0	1754	1754	0
50-2-3-3	1744	1744	0	1822	1822	0	1773	1773	0	1867	1867	0	1742	1742	0

Table B.7: Dupli-1, raw results.

Problems	1			2			3			4			5		
30-0-0-1	595313	1313	990	550206	1206	915	505166	1166	840	568181	1181	945	577247	1247	960
30-0-0-2	289167	1167	480	361275	1275	600	370258	1258	615	307171	1171	510	379303	1303	630
30-0-0-3	208286	1286	345	190232	1232	315	190221	1221	315	199287	1287	330	217261	1261	360
30-0-3-1	397428	1428	660	388448	1448	645	415438	1438	690	433504	1504	720	433540	1540	720
30-0-3-2	424419	1419	705	469471	1471	780	433399	1399	720	460499	1499	765	406358	1358	675
30-0-3-3	739352	1352	1230	721318	1318	1200	703321	1321	1170	757372	1372	1260	802373	1373	1335
30-2-0-1	649538	1538	1080	613494	1494	1020	667570	1570	1110	640492	1492	1065	613540	1540	1020
30-2-0-2	532510	1510	885	595706	1706	990	559586	1586	930	505504	1504	840	559598	1598	930
30-2-0-3	1378405	1405	2295	1378389	1389	2295	1387659	1659	2310	1387511	1511	2310	1405566	1566	2340
30-2-3-1	1153739	1739	1920	1180740	1740	1965	1081795	1795	1800	1117870	1870	1860	1099796	1796	1830
30-2-3-2	865661	1661	1440	847592	1592	1410	856766	1766	1425	847659	1659	1410	856662	1662	1425
30-2-3-3	685625	1625	1140	685639	1639	1140	712814	1814	1185	748746	1746	1245	676741	1741	1125
40-0-0-1	1103	1103	0	1272	1272	0	1115	1115	0	1136	1136	0	1125	1125	0
40-0-0-2	1132	1132	0	1081	1081	0	1053	1053	0	1208	1208	0	1145	1145	0
40-0-0-3	1114	1114	0	1105	1105	0	1214	1214	0	1093	1093	0	1149	1149	0
40-0-3-1	1406	1406	0	1401	1401	0	1421	1421	0	1422	1422	0	1360	1360	0
40-0-3-2	1440	1440	0	1364	1364	0	1418	1418	0	1364	1364	0	1399	1399	0
40-0-3-3	1376	1376	0	1445	1445	0	1367	1367	0	1452	1452	0	1480	1480	0
40-2-0-1	316876	1876	525	352922	1922	585	343753	1753	570	352771	1771	585	343828	1828	570
40-2-0-2	1775	1775	0	1906	1906	0	1723	1723	0	1852	1852	0	37911	1911	60
40-2-0-3	1826	1826	0	1755	1755	0	1943	1943	0	1897	1897	0	1741	1741	0
40-2-3-1	2082	2082	0	2078	2078	0	2056	2056	0	2095	2095	0	1902	1902	0
40-2-3-2	1903	1903	0	1825	1825	0	1714	1714	0	1847	1847	0	1906	1906	0
40-2-3-3	46894	1894	75	92167	2167	150	83019	2019	135	47064	2064	75	38058	2058	60
50-0-0-1	1103	1103	0	1211	1211	0	1105	1105	0	1138	1138	0	1139	1139	0
50-0-0-2	1210	1210	0	1164	1164	0	1171	1171	0	1108	1108	0	1219	1219	0
50-0-0-3	1125	1125	0	1054	1054	0	1210	1210	0	1090	1090	0	1098	1098	0
50-0-3-1	1451	1451	0	1422	1422	0	1369	1369	0	1467	1467	0	1409	1409	0
50-0-3-2	1482	1482	0	1374	1374	0	1496	1496	0	1481	1481	0	1384	1384	0
50-0-3-3	1455	1455	0	1455	1455	0	1401	1401	0	1453	1453	0	1449	1449	0
50-2-0-1	1575	1575	0	1562	1562	0	1491	1491	0	1461	1461	0	1549	1549	0
50-2-0-2	1291	1291	0	1359	1359	0	1352	1352	0	1461	1461	0	1300	1300	0
50-2-0-3	1479	1479	0	1427	1427	0	1380	1380	0	1475	1475	0	1421	1421	0
50-2-3-1	1752	1752	0	1744	1744	0	1726	1726	0	1651	1651	0	1752	1752	0
50-2-3-2	1825	1825	0	2052	2052	0	1946	1946	0	1910	1910	0	1828	1828	0
50-2-3-3	1874	1874	0	1819	1819	0	1844	1844	0	1862	1862	0	1857	1857	0

Table B.8: Dupli-2, raw results.

Problems	1			2			3			4			5		
30-0-0-1	523158	1158	870	541227	1227	900	577248	1248	960	577247	1247	960	550189	1189	915
30-0-0-2	307145	1145	510	334229	1229	555	316209	1209	525	325192	1192	540	325189	1189	540
30-0-0-3	181106	1106	300	109092	1092	180	190247	1247	315	208225	1225	345	181137	1137	300
30-0-3-1	361402	1402	600	334345	1345	555	379440	1440	630	379394	1394	630	289268	1268	480
30-0-3-2	370350	1350	615	397379	1379	660	343298	1298	570	379322	1322	630	379337	1337	630
30-0-3-3	730296	1296	1215	694293	1293	1155	748334	1334	1245	667240	1240	1110	721327	1327	1200
30-2-0-1	622515	1515	1035	586430	1430	975	577438	1438	960	559421	1421	930	577393	1393	960
30-2-0-2	568531	1531	945	541466	1466	900	523410	1410	870	514433	1433	855	604581	1581	1005
30-2-0-3	1414495	1495	2355	1405462	1462	2340	1378369	1369	2295	1396593	1593	2325	1387458	1458	2310
30-2-3-1	1099570	1570	1830	1090556	1556	1815	1144737	1737	1905	1135582	1582	1890	1153547	1547	1920
30-2-3-2	775523	1523	1290	793558	1558	1320	820581	1581	1365	820634	1634	1365	820580	1580	1365
30-2-3-3	730610	1610	1215	694566	1566	1155	712613	1613	1185	712629	1629	1185	739595	1595	1230
40-0-0-1	1232	1232	0	1175	1175	0	1162	1162	0	1212	1212	0	1104	1104	0
40-0-0-2	1194	1194	0	1202	1202	0	1122	1122	0	1142	1142	0	1201	1201	0
40-0-0-3	1101	1101	0	1236	1236	0	1129	1129	0	1182	1182	0	1186	1186	0
40-0-3-1	1355	1355	0	1400	1400	0	1393	1393	0	1378	1378	0	1377	1377	0
40-0-3-2	1320	1320	0	1340	1340	0	1366	1366	0	1294	1294	0	1342	1342	0
40-0-3-3	1417	1417	0	1342	1342	0	1516	1516	0	1441	1441	0	1467	1467	0
40-2-0-1	361799	1799	600	334685	1685	555	352687	1687	585	361793	1793	600	352686	1686	585
40-2-0-2	1623	1623	0	1755	1755	0	1905	1905	0	1739	1739	0	1675	1675	0
40-2-0-3	1651	1651	0	1769	1769	0	1642	1642	0	1591	1591	0	1744	1744	0
40-2-3-1	2130	2130	0	1944	1944	0	1878	1878	0	2069	2069	0	1996	1996	0
40-2-3-2	1670	1670	0	1782	1782	0	1726	1726	0	1669	1669	0	1682	1682	0
40-2-3-3	1864	1864	0	55910	1910	90	55933	1933	90	91829	1829	150	119042	2042	195
50-0-0-1	1330	1330	0	1193	1193	0	1280	1280	0	1261	1261	0	1168	1168	0
50-0-0-2	1196	1196	0	1210	1210	0	1133	1133	0	1158	1158	0	1159	1159	0
50-0-0-3	1138	1138	0	1177	1177	0	1091	1091	0	1095	1095	0	1260	1260	0
50-0-3-1	1442	1442	0	1376	1376	0	1421	1421	0	1427	1427	0	1482	1482	0
50-0-3-2	1440	1440	0	1503	1503	0	1532	1532	0	1342	1342	0	1453	1453	0
50-0-3-3	1436	1436	0	1429	1429	0	1495	1495	0	1510	1510	0	1477	1477	0
50-2-0-1	1554	1554	0	1513	1513	0	1610	1610	0	1551	1551	0	1603	1603	0
50-2-0-2	1410	1410	0	1445	1445	0	1341	1341	0	1304	1304	0	1431	1431	0
50-2-0-3	1498	1498	0	1529	1529	0	1391	1391	0	1362	1362	0	1509	1509	0
50-2-3-1	1646	1646	0	1672	1672	0	1650	1650	0	1764	1764	0	1647	1647	0
50-2-3-2	1889	1889	0	1898	1898	0	1856	1856	0	1863	1863	0	1926	1926	0
50-2-3-3	1839	1839	0	1872	1872	0	1893	1893	0	1877	1877	0	1906	1906	0

Table B.9: Direct4-s:200+repair, raw results.

Problems	1			2			3			4			5		
30-0-0-1	577195	1195	960	604246	1246	1005	613290	1290	1020	640290	1290	1065	640333	1333	1065
30-0-0-2	397262	1262	660	397239	1239	660	406292	1292	675	379235	1235	630	388279	1279	645
30-0-0-3	244268	1268	405	262316	1316	435	271365	1365	450	235275	1275	390	244304	1304	405
30-0-3-1	298260	1260	495	352353	1353	585	298257	1257	495	280246	1246	465	334282	1282	555
30-0-3-2	388386	1386	645	343255	1255	570	307308	1308	510	379376	1376	630	388350	1350	645
30-0-3-3	703251	1251	1170	613135	1135	1020	694282	1282	1155	730342	1342	1215	685268	1268	1140
30-2-0-1	712632	1632	1185	622519	1519	1035	721609	1609	1200	685475	1475	1140	676487	1487	1125
30-2-0-2	613709	1709	1020	577680	1680	960	604656	1656	1005	586666	1666	975	595746	1746	990
30-2-0-3	1387545	1545	2310	1441623	1623	2400	1423566	1566	2370	1432620	1620	2385	1414558	1558	2355
30-2-3-1	1090588	1588	1815	1072631	1631	1785	1126620	1620	1875	1117663	1663	1860	1081669	1669	1800
30-2-3-2	829634	1634	1380	793600	1600	1320	748600	1600	1245	757601	1601	1260	811581	1581	1350
30-2-3-3	694596	1596	1155	649551	1551	1080	649513	1513	1080	676542	1542	1125	676555	1555	1125
40-0-0-1	1144	1144	0	1252	1252	0	1192	1192	0	1255	1255	0	1278	1278	0
40-0-0-2	1174	1174	0	1123	1123	0	1161	1161	0	1252	1252	0	1172	1172	0
40-0-0-3	1212	1212	0	1303	1303	0	1136	1136	0	1204	1204	0	1169	1169	0
40-0-3-1	1449	1449	0	1323	1323	0	1342	1342	0	1459	1459	0	1319	1319	0
40-0-3-2	1412	1412	0	1232	1232	0	1326	1326	0	1295	1295	0	1369	1369	0
40-0-3-3	1456	1456	0	1414	1414	0	1351	1351	0	1444	1444	0	1407	1407	0
40-2-0-1	361970	1970	600	424899	1899	705	379939	1939	630	343790	1790	570	379865	1865	630
40-2-0-2	1895	1895	0	1655	1655	0	1735	1735	0	2002	2002	0	1745	1745	0
40-2-0-3	1824	1824	0	1911	1911	0	1833	1833	0	1611	1611	0	1926	1926	0
40-2-3-1	1898	1898	0	1859	1859	0	1921	1921	0	1823	1823	0	1815	1815	0
40-2-3-2	1739	1739	0	1738	1738	0	1618	1618	0	1632	1632	0	1614	1614	0
40-2-3-3	19844	1844	30	1820	1820	0	28906	1906	45	46898	1898	75	19837	1837	30
50-0-0-1	1315	1315	0	1297	1297	0	1234	1234	0	1297	1297	0	1342	1342	0
50-0-0-2	1262	1262	0	1288	1288	0	1216	1216	0	1239	1239	0	1271	1271	0
50-0-0-3	1222	1222	0	1206	1206	0	1297	1297	0	1193	1193	0	1185	1185	0
50-0-3-1	1374	1374	0	1383	1383	0	1476	1476	0	1471	1471	0	1410	1410	0
50-0-3-2	1439	1439	0	1394	1394	0	1368	1368	0	1405	1405	0	1327	1327	0
50-0-3-3	1494	1494	0	1370	1370	0	1439	1439	0	1419	1419	0	1493	1493	0
50-2-0-1	1627	1627	0	1597	1597	0	1637	1637	0	1527	1527	0	1604	1604	0
50-2-0-2	1459	1459	0	1440	1440	0	1445	1445	0	1414	1414	0	1472	1472	0
50-2-0-3	1415	1415	0	1390	1390	0	1465	1465	0	1425	1425	0	1433	1433	0
50-2-3-1	1701	1701	0	1762	1762	0	1587	1587	0	1552	1552	0	1609	1609	0
50-2-3-2	1785	1785	0	1861	1861	0	1722	1722	0	1812	1812	0	1942	1942	0
50-2-3-3	1815	1815	0	1811	1811	0	1754	1754	0	1845	1845	0	1742	1742	0

Table B.10: Dupli-1+repair, raw results.

Problems	1			2			3			4			5		
30-0-0-1	622222	1222	1035	631326	1326	1050	631313	1313	1050	541202	1202	900	622240	1240	1035
30-0-0-2	307147	1147	510	379260	1260	630	370282	1282	615	415294	1294	690	352237	1237	585
30-0-0-3	199240	1240	330	271287	1287	450	226256	1256	375	253313	1313	420	208247	1247	345
30-0-3-1	361289	1289	600	370328	1328	615	397421	1421	660	388391	1391	645	370372	1372	615
30-0-3-2	397377	1377	660	379361	1361	630	442327	1327	735	433350	1350	720	469415	1415	780
30-0-3-3	712323	1323	1185	676226	1226	1125	757379	1379	1260	703271	1271	1170	685237	1237	1140
30-2-0-1	685527	1527	1140	703489	1489	1170	694545	1545	1155	676538	1538	1125	721537	1537	1200
30-2-0-2	613584	1584	1020	595639	1639	990	622643	1643	1035	604579	1579	1005	568621	1621	945
30-2-0-3	1432505	1505	2385	1432471	1471	2385	1432507	1507	2385	1432634	1634	2385	1423616	1616	2370
30-2-3-1	1117723	1723	1860	1135678	1678	1890	1081590	1590	1800	1126573	1573	1875	1072575	1575	1785
30-2-3-2	829636	1636	1380	910690	1690	1515	910608	1608	1515	829511	1511	1380	775603	1603	1290
30-2-3-3	676545	1545	1125	721639	1639	1200	748600	1600	1245	721648	1648	1200	712512	1512	1185
40-0-0-1	1085	1085	0	1160	1160	0	1059	1059	0	1128	1128	0	1070	1070	0
40-0-0-2	1061	1061	0	1082	1082	0	1044	1044	0	1060	1060	0	1061	1061	0
40-0-0-3	986	986	0	1104	1104	0	1026	1026	0	978	978	0	1038	1038	0
40-0-3-1	1378	1378	0	1321	1321	0	1335	1335	0	1327	1327	0	1401	1401	0
40-0-3-2	1257	1257	0	1278	1278	0	1343	1343	0	1282	1282	0	1326	1326	0
40-0-3-3	1360	1360	0	1358	1358	0	1471	1471	0	1412	1412	0	1359	1359	0
40-2-0-1	370866	1866	615	352845	1845	585	388882	1882	645	370627	1627	615	370929	1929	615
40-2-0-2	1660	1660	0	1892	1892	0	1714	1714	0	1629	1629	0	1757	1757	0
40-2-0-3	1699	1699	0	1814	1814	0	1679	1679	0	1799	1799	0	1631	1631	0
40-2-3-1	1818	1818	0	1962	1962	0	2096	2096	0	1849	1849	0	2028	2028	0
40-2-3-2	1669	1669	0	1709	1709	0	1868	1868	0	1763	1763	0	1719	1719	0
40-2-3-3	46985	1985	75	55906	1906	90	64824	1824	105	1951	1951	0	64946	1946	105
50-0-0-1	1118	1118	0	1216	1216	0	1143	1143	0	1201	1201	0	1221	1221	0
50-0-0-2	1097	1097	0	1110	1110	0	1039	1039	0	1077	1077	0	1012	1012	0
50-0-0-3	1026	1026	0	1081	1081	0	1040	1040	0	1069	1069	0	1006	1006	0
50-0-3-1	1362	1362	0	1383	1383	0	1424	1424	0	1297	1297	0	1336	1336	0
50-0-3-2	1350	1350	0	1427	1427	0	1372	1372	0	1303	1303	0	1321	1321	0
50-0-3-3	1378	1378	0	1316	1316	0	1369	1369	0	1336	1336	0	1450	1450	0
50-2-0-1	1522	1522	0	1604	1604	0	1599	1599	0	1506	1506	0	1439	1439	0
50-2-0-2	1310	1310	0	1301	1301	0	1230	1230	0	1367	1367	0	1422	1422	0
50-2-0-3	1352	1352	0	1499	1499	0	1348	1348	0	1424	1424	0	1380	1380	0
50-2-3-1	1574	1574	0	1597	1597	0	1620	1620	0	1513	1513	0	1613	1613	0
50-2-3-2	1911	1911	0	1901	1901	0	1790	1790	0	1908	1908	0	1802	1802	0
50-2-3-3	1792	1792	0	1897	1897	0	1724	1724	0	1633	1633	0	1735	1735	0

Table B.11: Dupli-2+repair, raw results.

Problems	1			2			3			4			5		
30-0-0-1	973918	1918	1620	982869	1869	1635	964890	1890	1605	973925	1925	1620	982882	1882	1635
30-0-0-2	748926	1926	1245	784974	1974	1305	793962	1962	1320	766951	1951	1275	784968	1968	1305
30-0-0-3	613955	1955	1020	631968	1968	1050	632010	2010	1050	595929	1929	990	613992	1992	1020
30-0-3-1	757993	1993	1260	758009	2009	1260	748967	1967	1245	767014	2014	1275	785062	2062	1305
30-0-3-2	821011	2011	1365	821068	2068	1365	812072	2072	1350	821055	2055	1365	803023	2023	1335
30-0-3-3	1090903	1903	1815	1090884	1884	1815	1108919	1919	1845	1090926	1926	1815	1081943	1943	1800
30-2-0-1	901974	1974	1500	910967	1967	1515	910998	1998	1515	911029	2029	1515	910974	1974	1515
30-2-0-2	767054	2054	1275	767066	2066	1275	776063	2063	1290	776057	2057	1290	776066	2066	1290
30-2-0-3	1495836	1836	2490	1495845	1845	2490	1504872	1872	2505	1504810	1810	2505	1495877	1877	2490
30-2-3-1	1361186	2186	2265	1370027	2027	2280	1352164	2164	2250	1370176	2176	2280	1370108	2108	2280
30-2-3-2	1163096	2096	1935	1154147	2147	1920	1154056	2056	1920	1163081	2081	1935	1136054	2054	1890
30-2-3-3	901984	1984	1500	884083	2083	1470	920183	2183	1530	911141	2141	1515	929124	2124	1545
40-0-0-1	2272	2272	0	2272	2272	0	2251	2251	0	2265	2265	0	2174	2174	0
40-0-0-2	2183	2183	0	2235	2235	0	2260	2260	0	2245	2245	0	2232	2232	0
40-0-0-3	2166	2166	0	2205	2205	0	2204	2204	0	2168	2168	0	2190	2190	0
40-0-3-1	2306	2306	0	2333	2333	0	2315	2315	0	2313	2313	0	2309	2309	0
40-0-3-2	2205	2205	0	2216	2216	0	2223	2223	0	2175	2175	0	2181	2181	0
40-0-3-3	2356	2356	0	2426	2426	0	2412	2412	0	2380	2380	0	2339	2339	0
40-2-0-1	461248	2248	765	452312	2312	750	443139	2139	735	425304	2304	705	443374	2374	735
40-2-0-2	65155	2155	105	56199	2199	90	56219	2219	90	56219	2219	90	38244	2244	60
40-2-0-3	56272	2272	90	56379	2379	90	56330	2330	90	56369	2369	90	56321	2321	90
40-2-3-1	20561	2561	30	2573	2573	0	47581	2581	75	2480	2480	0	38451	2451	60
40-2-3-2	2320	2320	0	2255	2255	0	2226	2226	0	2310	2310	0	2285	2285	0
40-2-3-3	173288	2288	285	191347	2347	315	218421	2421	360	191351	2351	315	182433	2433	300
50-0-0-1	2317	2317	0	2310	2310	0	2309	2309	0	2300	2300	0	2333	2333	0
50-0-0-2	2236	2236	0	2255	2255	0	2230	2230	0	2251	2251	0	2204	2204	0
50-0-0-3	2241	2241	0	2225	2225	0	2237	2237	0	2258	2258	0	2212	2212	0
50-0-3-1	2279	2279	0	2284	2284	0	2260	2260	0	2296	2296	0	2263	2263	0
50-0-3-2	2335	2335	0	2393	2393	0	2365	2365	0	2398	2398	0	2335	2335	0
50-0-3-3	2338	2338	0	2343	2343	0	2321	2321	0	2323	2323	0	2304	2304	0
50-2-0-1	2156	2156	0	2232	2232	0	2215	2215	0	2209	2209	0	2108	2108	0
50-2-0-2	2116	2116	0	2097	2097	0	2105	2105	0	2111	2111	0	2110	2110	0
50-2-0-3	2133	2133	0	2117	2117	0	2075	2075	0	2141	2141	0	2132	2132	0
50-2-3-1	2220	2220	0	2175	2175	0	2171	2171	0	2185	2185	0	2171	2171	0
50-2-3-2	2313	2313	0	2392	2392	0	2358	2358	0	2397	2397	0	2313	2313	0
50-2-3-3	2412	2412	0	2388	2388	0	2352	2352	0	2390	2390	0	2386	2386	0

Table B.12: Random Search, raw results.

Problems	1			2			3			4			5		
30-0-0-1	577218	1218	960	595220	1220	990	586219	1219	975	586197	1197	975	559161	1161	930
30-0-0-2	388233	1233	645	388252	1252	645	406300	1300	675	442322	1322	735	370259	1259	615
30-0-0-3	271307	1307	450	298393	1393	495	208242	1242	345	235257	1257	390	208283	1283	345
30-0-3-1	451513	1513	750	433475	1475	720	460461	1461	765	460500	1500	765	442445	1445	735
30-0-3-2	514530	1530	855	505524	1524	840	487454	1454	810	523534	1534	870	460510	1510	765
30-0-3-3	784348	1348	1305	802373	1373	1335	811386	1386	1350	739295	1295	1230	757338	1338	1260
30-2-0-1	595393	1393	990	586392	1392	975	622423	1423	1035	595380	1380	990	622371	1371	1035
30-2-0-2	604535	1535	1005	568501	1501	945	514448	1448	855	586493	1493	975	532277	1277	885
30-2-0-3	1386946	946	2310	1395929	929	2325	1404936	936	2340	1395868	868	2325	1413951	951	2355
30-2-3-1	1207505	1505	2010	1279500	1500	2130	1225485	1485	2040	1252498	1498	2085	1162438	1438	1935
30-2-3-2	973518	1518	1620	892558	1558	1485	946487	1487	1575	865629	1629	1440	946561	1561	1575
30-2-3-3	865370	1370	1440	748474	1474	1245	685229	1229	1140	748346	1346	1245	757368	1368	1260
40-0-0-1	965	965	0	895	895	0	990	990	0	820	820	0	932	932	0
40-0-0-2	907	907	0	958	958	0	943	943	0	906	906	0	772	772	0
40-0-0-3	1044	1044	0	991	991	0	795	795	0	950	950	0	891	891	0
40-0-3-1	1303	1303	0	1288	1288	0	1290	1290	0	1305	1305	0	1366	1366	0
40-0-3-2	1109	1109	0	1169	1169	0	1167	1167	0	1119	1119	0	1269	1269	0
40-0-3-3	1278	1278	0	1281	1281	0	1279	1279	0	1353	1353	0	1334	1334	0
40-2-0-1	316020	1020	525	352012	1012	585	369978	978	615	333998	998	555	306990	990	510
40-2-0-2	55093	1093	90	993	993	0	1165	1165	0	1095	1095	0	1125	1125	0
40-2-0-3	1065	1065	0	1187	1187	0	1120	1120	0	1151	1151	0	1026	1026	0
40-2-3-1	46389	1389	75	73490	1490	120	55464	1464	90	100377	1377	165	1294	1294	0
40-2-3-2	1362	1362	0	1402	1402	0	1277	1277	0	1308	1308	0	1253	1253	0
40-2-3-3	235368	1368	390	100320	1320	165	154425	1425	255	163369	1369	270	136329	1329	225
50-0-0-1	950	950	0	1010	1010	0	1031	1031	0	1039	1039	0	924	924	0
50-0-0-2	849	849	0	940	940	0	872	872	0	986	986	0	854	854	0
50-0-0-3	781	781	0	796	796	0	872	872	0	802	802	0	875	875	0
50-0-3-1	1167	1167	0	1231	1231	0	1158	1158	0	1197	1197	0	1129	1129	0
50-0-3-2	1200	1200	0	1230	1230	0	1170	1170	0	1310	1310	0	1184	1184	0
50-0-3-3	1126	1126	0	1250	1250	0	1222	1222	0	1083	1083	0	1153	1153	0
50-2-0-1	1032	1032	0	1037	1037	0	1086	1086	0	1081	1081	0	1101	1101	0
50-2-0-2	845	845	0	880	880	0	809	809	0	934	934	0	909	909	0
50-2-0-3	1012	1012	0	956	956	0	899	899	0	1033	1033	0	936	936	0
50-2-3-1	1158	1158	0	1262	1262	0	1237	1237	0	1293	1293	0	1270	1270	0
50-2-3-2	1377	1377	0	1387	1387	0	1327	1327	0	1414	1414	0	1366	1366	0
50-2-3-3	1249	1249	0	1324	1324	0	1286	1286	0	1314	1314	0	1350	1350	0

Table B.13: Hill-climbing, raw results.

Problems	1			2			3			4			5		
30-0-0-1	433029	1029	720	451038	1038	750	442058	1058	735	451083	1083	750	424025	1025	705
30-0-0-2	235090	1090	390	262087	1087	435	289123	1123	480	253077	1077	420	253101	1101	420
30-0-0-3	118158	1158	195	118144	1144	195	100118	1118	165	100131	1131	165	100115	1115	165
30-0-3-1	325379	1379	540	370414	1414	615	343381	1381	570	307343	1343	510	343390	1390	570
30-0-3-2	415468	1468	690	325298	1298	540	316301	1301	525	343336	1336	570	352340	1340	585
30-0-3-3	622218	1218	1035	622198	1198	1035	658265	1265	1095	640226	1226	1065	649223	1223	1080
30-2-0-1	496342	1342	825	505381	1381	840	523398	1398	870	487335	1335	810	514418	1418	855
30-2-0-2	468982	982	780	450913	913	750	460206	1206	765	487047	1047	810	460042	1042	765
30-2-0-3	1359744	744	2265	1359754	754	2265	1341751	751	2235	1359781	781	2265	1350816	816	2250
30-2-3-1	1054143	1143	1755	1018079	1079	1695	1045124	1124	1740	1054227	1227	1755	1090146	1146	1815
30-2-3-2	748576	1576	1245	811626	1626	1350	757567	1567	1260	811576	1576	1350	721604	1604	1200
30-2-3-3	676221	1221	1125	730157	1157	1215	667180	1180	1110	712105	1105	1185	703237	1237	1170
40-0-0-1	821	821	0	751	751	0	768	768	0	759	759	0	741	741	0
40-0-0-2	824	824	0	747	747	0	780	780	0	772	772	0	802	802	0
40-0-0-3	746	746	0	745	745	0	744	744	0	782	782	0	788	788	0
40-0-3-1	977	977	0	949	949	0	982	982	0	927	927	0	984	984	0
40-0-3-2	884	884	0	854	854	0	892	892	0	931	931	0	887	887	0
40-0-3-3	963	963	0	993	993	0	1045	1045	0	1000	1000	0	989	989	0
40-2-0-1	279991	991	465	261970	970	435	243960	960	405	243968	968	405	243966	966	405
40-2-0-2	921	921	0	869	869	0	864	864	0	884	884	0	955	955	0
40-2-0-3	943	943	0	915	915	0	915	915	0	941	941	0	913	913	0
40-2-3-1	1131	1131	0	1147	1147	0	1192	1192	0	1151	1151	0	1156	1156	0
40-2-3-2	1037	1037	0	940	940	0	1031	1031	0	1090	1090	0	1011	1011	0
40-2-3-3	1273	1273	0	28172	1172	45	1218	1218	0	1158	1158	0	37189	1189	60
50-0-0-1	814	814	0	842	842	0	792	792	0	837	837	0	808	808	0
50-0-0-2	827	827	0	762	762	0	868	868	0	811	811	0	819	819	0
50-0-0-3	791	791	0	762	762	0	750	750	0	774	774	0	774	774	0
50-0-3-1	979	979	0	924	924	0	923	923	0	922	922	0	958	958	0
50-0-3-2	984	984	0	958	958	0	969	969	0	980	980	0	983	983	0
50-0-3-3	974	974	0	939	939	0	1016	1016	0	960	960	0	972	972	0
50-2-0-1	899	899	0	882	882	0	901	901	0	906	906	0	900	900	0
50-2-0-2	713	713	0	722	722	0	729	729	0	728	728	0	698	698	0
50-2-0-3	825	825	0	806	806	0	832	832	0	823	823	0	846	846	0
50-2-3-1	1024	1024	0	1014	1014	0	980	980	0	1002	1002	0	982	982	0
50-2-3-2	1116	1116	0	1135	1135	0	1152	1152	0	1138	1138	0	1141	1141	0
50-2-3-3	1120	1120	0	1094	1094	0	1090	1090	0	1139	1139	0	1103	1103	0

Table B.14: Simulated Annealing, raw results.

Problems	1			2			3			4			5		
30-0-0-1	541177	1177	900	568217	1217	945	568211	1211	945	577238	1238	960	541168	1168	900
30-0-0-2	361255	1255	600	343175	1175	570	397285	1285	660	361240	1240	600	280098	1098	465
30-0-0-3	172185	1185	285	262342	1342	435	208267	1267	345	226274	1274	375	163174	1174	270
30-0-3-1	379425	1425	630	370415	1415	615	343376	1376	570	316325	1325	525	280302	1302	465
30-0-3-2	352323	1323	585	388362	1362	645	406398	1398	675	343285	1285	570	406406	1406	675
30-0-3-3	685259	1259	1140	667265	1265	1110	658215	1215	1095	712293	1293	1185	658210	1210	1095
30-2-0-1	523338	1338	870	559388	1388	930	550290	1290	915	577401	1401	960	541372	1372	900
30-2-0-2	468932	932	780	496031	1031	825	505026	1026	840	495906	906	825	496008	1008	825
30-2-0-3	1350904	904	2250	1386915	915	2310	1386912	912	2310	1368901	901	2280	1350890	890	2250
30-2-3-1	1081172	1172	1800	1036147	1147	1725	1090247	1247	1815	1090128	1128	1815	1090228	1228	1815
30-2-3-2	829685	1685	1380	802548	1548	1335	793490	1490	1320	775462	1462	1290	766621	1621	1275
30-2-3-3	676128	1128	1125	649167	1167	1080	658150	1150	1095	703166	1166	1170	676198	1198	1125
40-0-0-1	1171	1171	0	1187	1187	0	1132	1132	0	1177	1177	0	1121	1121	0
40-0-0-2	1179	1179	0	1143	1143	0	1120	1120	0	1214	1214	0	1225	1225	0
40-0-0-3	1106	1106	0	1023	1023	0	1094	1094	0	1045	1045	0	1128	1128	0
40-0-3-1	1193	1193	0	1157	1157	0	1228	1228	0	1149	1149	0	1133	1133	0
40-0-3-2	1082	1082	0	1035	1035	0	1098	1098	0	1094	1094	0	1081	1081	0
40-0-3-3	1147	1147	0	1201	1201	0	1210	1210	0	1182	1182	0	1258	1258	0
40-2-0-1	280079	1079	465	235098	1098	390	253041	1041	420	244082	1082	405	280048	1048	465
40-2-0-2	980	980	0	1102	1102	0	1047	1047	0	1057	1057	0	1017	1017	0
40-2-0-3	1083	1083	0	1055	1055	0	1052	1052	0	1105	1105	0	1065	1065	0
40-2-3-1	1214	1214	0	1219	1219	0	1203	1203	0	1206	1206	0	1252	1252	0
40-2-3-2	1065	1065	0	1086	1086	0	1020	1020	0	1014	1014	0	1098	1098	0
40-2-3-3	64216	1216	105	64235	1235	105	37264	1264	60	1265	1265	0	64247	1247	105
50-0-0-1	1287	1287	0	1249	1249	0	1290	1290	0	1181	1181	0	1236	1236	0
50-0-0-2	1103	1103	0	1174	1174	0	1269	1269	0	1157	1157	0	1149	1149	0
50-0-0-3	1056	1056	0	1059	1059	0	1127	1127	0	1092	1092	0	1154	1154	0
50-0-3-1	1207	1207	0	1272	1272	0	1227	1227	0	1233	1233	0	1142	1142	0
50-0-3-2	1185	1185	0	1245	1245	0	1225	1225	0	1203	1203	0	1138	1138	0
50-0-3-3	1090	1090	0	1170	1170	0	1228	1228	0	1217	1217	0	1159	1159	0
50-2-0-1	1131	1131	0	1048	1048	0	1071	1071	0	1071	1071	0	1080	1080	0
50-2-0-2	959	959	0	912	912	0	1036	1036	0	978	978	0	970	970	0
50-2-0-3	994	994	0	1043	1043	0	1012	1012	0	1039	1039	0	966	966	0
50-2-3-1	1059	1059	0	1072	1072	0	1080	1080	0	1102	1102	0	1083	1083	0
50-2-3-2	1184	1184	0	1191	1191	0	1209	1209	0	1205	1205	0	1157	1157	0
50-2-3-3	1130	1130	0	1168	1168	0	1166	1166	0	1143	1143	0	1165	1165	0

Table B.15: Tabu Search, raw results.

Problems	1			2			3			4			5		
30-0-0-1	414983	983	690	451092	1092	750	433016	1016	720	424015	1015	705	369951	951	615
30-0-0-2	135888	888	225	190007	1007	315	217045	1045	360	199033	1033	330	217040	1040	360
30-0-0-3	127090	1090	210	145140	1140	240	73049	1049	120	37005	1005	60	73082	1082	120
30-0-3-1	235186	1186	390	271225	1225	450	262271	1271	435	262161	1161	435	244236	1236	405
30-0-3-2	307216	1216	510	298240	1240	495	262217	1217	435	316257	1257	525	235160	1160	390
30-0-3-3	631200	1200	1050	613207	1207	1020	604167	1167	1005	604188	1188	1005	604122	1122	1005
30-2-0-1	523259	1259	870	460174	1174	765	460175	1175	765	460267	1267	765	514318	1318	855
30-2-0-2	469289	1289	780	469411	1411	780	496402	1402	825	487304	1304	810	505381	1381	840
30-2-0-3	1324101	1101	2205	1333121	1121	2220	1324093	1093	2205	1315067	1067	2190	1342138	1138	2235
30-2-3-1	1009417	1417	1680	1045579	1579	1740	1045498	1498	1740	1000493	1493	1665	982357	1357	1635
30-2-3-2	703433	1433	1170	703421	1421	1170	676456	1456	1125	802612	1612	1335	739531	1531	1230
30-2-3-3	613366	1366	1020	604371	1371	1005	613494	1494	1020	613388	1388	1020	595448	1448	990
40-0-0-1	924	924	0	971	971	0	846	846	0	950	950	0	883	883	0
40-0-0-2	876	876	0	848	848	0	878	878	0	886	886	0	875	875	0
40-0-0-3	910	910	0	828	828	0	825	825	0	841	841	0	812	812	0
40-0-3-1	1081	1081	0	1108	1108	0	1155	1155	0	1147	1147	0	1119	1119	0
40-0-3-2	1116	1116	0	1060	1060	0	1173	1173	0	1059	1059	0	1043	1043	0
40-0-3-3	1141	1141	0	1188	1188	0	1088	1088	0	1167	1167	0	1200	1200	0
40-2-0-1	271326	1326	450	280460	1460	465	289509	1509	480	253397	1397	420	262513	1513	435
40-2-0-2	1363	1363	0	1331	1331	0	1362	1362	0	1390	1390	0	1307	1307	0
40-2-0-3	1386	1386	0	1309	1309	0	1368	1368	0	1288	1288	0	1212	1212	0
40-2-3-1	1577	1577	0	1634	1634	0	1490	1490	0	1554	1554	0	1529	1529	0
40-2-3-2	1541	1541	0	1514	1514	0	1385	1385	0	1387	1387	0	1596	1596	0
40-2-3-3	1640	1640	0	1840	1840	0	1744	1744	0	1785	1785	0	1656	1656	0
50-0-0-1	904	904	0	919	919	0	929	929	0	1002	1002	0	973	973	0
50-0-0-2	909	909	0	902	902	0	878	878	0	856	856	0	932	932	0
50-0-0-3	871	871	0	839	839	0	866	866	0	889	889	0	846	846	0
50-0-3-1	1127	1127	0	1202	1202	0	1117	1117	0	1241	1241	0	1121	1121	0
50-0-3-2	1089	1089	0	1122	1122	0	1108	1108	0	1142	1142	0	1237	1237	0
50-0-3-3	1108	1108	0	1180	1180	0	1183	1183	0	1175	1175	0	1108	1108	0
50-2-0-1	1248	1248	0	1195	1195	0	1251	1251	0	1283	1283	0	1323	1323	0
50-2-0-2	989	989	0	1055	1055	0	1011	1011	0	1139	1139	0	1175	1175	0
50-2-0-3	1191	1191	0	1174	1174	0	1105	1105	0	1220	1220	0	1155	1155	0
50-2-3-1	1404	1404	0	1355	1355	0	1402	1402	0	1416	1416	0	1312	1312	0
50-2-3-2	1527	1527	0	1578	1578	0	1558	1558	0	1561	1561	0	1585	1585	0
50-2-3-3	1468	1468	0	1584	1584	0	1438	1438	0	1498	1498	0	1502	1502	0

Table B.16: Genetic Algorithm (CPU intensive runs), raw results.

Problems	1			2			3			4			5		
30-0-0-1	811507	1507	1350	703398	1398	1170	775480	1480	1290	649338	1338	1080	784530	1530	1305
30-0-0-2	550472	1472	915	523399	1399	870	505396	1396	840	541420	1420	900	487364	1364	810
30-0-0-3	325358	1358	540	451571	1571	750	325353	1353	540	415431	1431	690	343449	1449	570
30-0-3-1	613618	1618	1020	622589	1589	1035	667725	1725	1110	523446	1446	870	559425	1425	930
30-0-3-2	640361	1361	1065	640392	1392	1065	631591	1591	1050	604435	1435	1005	577461	1461	960
30-0-3-3	892499	1499	1485	919447	1447	1530	910526	1526	1515	1000628	1628	1665	901454	1454	1500
30-2-0-1	703196	1196	1170	820602	1602	1365	694243	1243	1155	784517	1517	1305	784536	1536	1305
30-2-0-2	631257	1257	1050	640439	1439	1065	676147	1147	1125	685401	1401	1140	613108	1108	1020
30-2-0-3	1495101	1101	2490	1476993	993	2460	1567055	1055	2610	1566915	915	2610	1495022	1022	2490
30-2-3-1	1315346	1346	2190	1414423	1423	2355	1414448	1448	2355	1459534	1534	2430	1306482	1482	2175
30-2-3-2	1198520	1520	1995	1225431	1431	2040	1342378	1378	2235	1144614	1614	1905	1018502	1502	1695
30-2-3-3	982361	1361	1635	910418	1418	1515	856348	1348	1425	982307	1307	1635	847351	1351	1410
40-0-0-1	793	793	0	885	885	0	865	865	0	873	873	0	873	873	0
40-0-0-2	853	853	0	820	820	0	701	701	0	810	810	0	875	875	0
40-0-0-3	779	779	0	707	707	0	715	715	0	785	785	0	707	707	0
40-0-3-1	1037	1037	0	990	990	0	1031	1031	0	974	974	0	998	998	0
40-0-3-2	1128	1128	0	997	997	0	988	988	0	1000	1000	0	1204	1204	0
40-0-3-3	1011	1011	0	1021	1021	0	1144	1144	0	1016	1016	0	1020	1020	0
40-2-0-1	622062	1062	1035	514015	1015	855	577057	1057	960	514049	1049	855	559052	1052	930
40-2-0-2	72961	961	120	117964	964	195	63999	999	105	63986	986	105	54977	977	90
40-2-0-3	136021	1021	225	63995	995	105	63976	976	105	127073	1073	210	63962	962	105
40-2-3-1	109363	1363	180	1207	1207	0	55206	1206	90	1357	1357	0	109304	1304	180
40-2-3-2	1168	1168	0	1127	1127	0	64301	1301	105	1136	1136	0	1188	1188	0
40-2-3-3	208283	1283	345	343291	1291	570	325277	1277	540	190304	1304	315	325288	1288	540
50-0-0-1	820	820	0	799	799	0	873	873	0	862	862	0	892	892	0
50-0-0-2	768	768	0	735	735	0	757	757	0	791	791	0	700	700	0
50-0-0-3	669	669	0	679	679	0	738	738	0	744	744	0	765	765	0
50-0-3-1	1016	1016	0	987	987	0	983	983	0	1199	1199	0	967	967	0
50-0-3-2	1031	1031	0	1097	1097	0	1050	1050	0	970	970	0	1018	1018	0
50-0-3-3	954	954	0	931	931	0	1002	1002	0	959	959	0	981	981	0
50-2-0-1	924	924	0	918	918	0	908	908	0	953	953	0	895	895	0
50-2-0-2	785	785	0	846	846	0	793	793	0	751	751	0	748	748	0
50-2-0-3	893	893	0	916	916	0	898	898	0	949	949	0	864	864	0
50-2-3-1	1050	1050	0	1129	1129	0	1086	1086	0	1084	1084	0	1115	1115	0
50-2-3-2	1322	1322	0	46223	1223	75	1223	1223	0	1319	1319	0	1343	1343	0
50-2-3-3	1338	1338	0	1303	1303	0	1127	1127	0	1212	1212	0	1378	1378	0

Table B.17: Hill-climbing (CPU intensive runs), raw results.

Problems	1			2			3			4			5		
30-0-0-1	955853	1853	1590	946891	1891	1575	937881	1881	1560	955874	1874	1590	955859	1859	1590
30-0-0-2	757914	1914	1260	748901	1901	1245	739902	1902	1230	739889	1889	1230	748892	1892	1245
30-0-0-3	577896	1896	960	586919	1919	975	577921	1921	960	586974	1974	975	595948	1948	990
30-0-3-1	730988	1988	1215	685959	1959	1140	731003	2003	1215	730973	1973	1215	721970	1970	1200
30-0-3-2	775996	1996	1290	776014	2014	1290	748946	1946	1245	776032	2032	1290	775999	1999	1290
30-0-3-3	1045888	1888	1740	1063873	1873	1770	1054893	1893	1755	1054890	1890	1755	1081901	1901	1800
30-2-0-1	865927	1927	1440	865900	1900	1440	865961	1961	1440	874916	1916	1455	838895	1895	1395
30-2-0-2	740024	2024	1230	740035	2035	1230	739986	1986	1230	740003	2003	1230	740016	2016	1230
30-2-0-3	1486842	1842	2475	1486786	1786	2475	1477819	1819	2460	1477949	1949	2460	1486879	1879	2475
30-2-3-1	1298194	2194	2160	1325277	2277	2205	1325197	2197	2205	1325108	2108	2205	1298250	2250	2160
30-2-3-2	1100099	2099	1830	1100008	2008	1830	1118088	2088	1860	1127064	2064	1875	1118185	2185	1860
30-2-3-3	830063	2063	1380	866069	2069	1440	839097	2097	1395	839038	2038	1395	857088	2088	1425
40-0-0-1	2214	2214	0	2174	2174	0	2193	2193	0	2234	2234	0	2200	2200	0
40-0-0-2	2169	2169	0	2203	2203	0	2196	2196	0	2179	2179	0	2185	2185	0
40-0-0-3	2137	2137	0	2125	2125	0	2121	2121	0	2161	2161	0	2137	2137	0
40-0-3-1	2234	2234	0	2246	2246	0	2260	2260	0	2226	2226	0	2261	2261	0
40-0-3-2	2118	2118	0	2158	2158	0	2157	2157	0	2154	2154	0	2156	2156	0
40-0-3-3	2372	2372	0	2328	2328	0	2376	2376	0	2271	2271	0	2358	2358	0
40-2-0-1	416151	2151	690	407332	2332	675	434313	2313	720	434077	2077	720	389253	2253	645
40-2-0-2	38286	2286	60	29371	2371	45	29261	2261	45	2233	2233	0	38213	2213	60
40-2-0-3	29379	2379	45	2380	2380	0	38384	2384	60	29306	2306	45	2401	2401	0
40-2-3-1	2583	2583	0	2515	2515	0	2418	2418	0	2451	2451	0	2507	2507	0
40-2-3-2	2119	2119	0	2184	2184	0	2215	2215	0	2225	2225	0	2238	2238	0
40-2-3-3	146364	2364	240	128271	2271	210	164383	2383	270	155356	2356	255	146403	2403	240
50-0-0-1	2238	2238	0	2248	2248	0	2250	2250	0	2252	2252	0	2252	2252	0
50-0-0-2	2198	2198	0	2144	2144	0	2147	2147	0	2151	2151	0	2178	2178	0
50-0-0-3	2186	2186	0	2158	2158	0	2190	2190	0	2149	2149	0	2174	2174	0
50-0-3-1	2205	2205	0	2243	2243	0	2228	2228	0	2237	2237	0	2257	2257	0
50-0-3-2	2294	2294	0	2295	2295	0	2310	2310	0	2258	2258	0	2265	2265	0
50-0-3-3	2275	2275	0	2245	2245	0	2262	2262	0	2270	2270	0	2249	2249	0
50-2-0-1	2134	2134	0	2185	2185	0	2148	2148	0	2134	2134	0	2156	2156	0
50-2-0-2	2027	2027	0	2039	2039	0	2065	2065	0	2021	2021	0	2009	2009	0
50-2-0-3	2079	2079	0	2085	2085	0	2063	2063	0	2075	2075	0	2072	2072	0
50-2-3-1	2107	2107	0	2152	2152	0	2165	2165	0	2118	2118	0	2167	2167	0
50-2-3-2	2348	2348	0	2321	2321	0	2322	2322	0	2343	2343	0	2332	2332	0
50-2-3-3	2378	2378	0	2317	2317	0	2335	2335	0	2316	2316	0	2342	2342	0

Table B.18: Random Search (CPU intensive runs), raw results.

Problems	1			2			3			4			5		
30-0-0-1	415020	1020	690	397005	1005	660	387985	985	645	351918	918	585	396991	991	660
30-0-0-2	217078	1078	360	190030	1030	315	199014	1014	330	172010	1010	285	190029	1029	315
30-0-0-3	100131	1131	165	100143	1143	165	73113	1113	120	118181	1181	195	145213	1213	240
30-0-3-1	316355	1355	525	289288	1288	480	280269	1269	465	361437	1437	600	325397	1397	540
30-0-3-2	316308	1308	525	316279	1279	525	325318	1318	540	370394	1394	615	361360	1360	600
30-0-3-3	550093	1093	915	649231	1231	1080	604207	1207	1005	649252	1252	1080	595197	1197	990
30-2-0-1	487359	1359	810	460306	1306	765	478329	1329	795	496379	1379	825	523411	1411	870
30-2-0-2	441843	843	735	441852	852	735	450843	843	750	468853	853	780	441821	821	735
30-2-0-3	1341757	757	2235	1332698	698	2220	1341717	717	2235	1350715	715	2250	1332691	691	2220
30-2-3-1	1063154	1154	1770	991022	1022	1650	1018091	1091	1695	1081132	1132	1800	1054127	1127	1755
30-2-3-2	739624	1624	1230	685532	1532	1140	811649	1649	1350	721582	1582	1200	793589	1589	1320
30-2-3-3	667112	1112	1110	586084	1084	975	667139	1139	1110	649123	1123	1080	640036	1036	1065
40-0-0-1	706	706	0	693	693	0	678	678	0	695	695	0	708	708	0
40-0-0-2	703	703	0	668	668	0	692	692	0	682	682	0	692	692	0
40-0-0-3	681	681	0	670	670	0	672	672	0	686	686	0	646	646	0
40-0-3-1	851	851	0	881	881	0	876	876	0	866	866	0	866	866	0
40-0-3-2	823	823	0	832	832	0	862	862	0	808	808	0	783	783	0
40-0-3-3	919	919	0	922	922	0	917	917	0	894	894	0	917	917	0
40-2-0-1	234947	947	390	261962	962	435	225949	949	375	243928	928	405	225949	949	375
40-2-0-2	814	814	0	809	809	0	812	812	0	820	820	0	782	782	0
40-2-0-3	860	860	0	852	852	0	847	847	0	857	857	0	853	853	0
40-2-3-1	1072	1072	0	1042	1042	0	1056	1056	0	1067	1067	0	1078	1078	0
40-2-3-2	953	953	0	959	959	0	941	941	0	975	975	0	938	938	0
40-2-3-3	1143	1143	0	1056	1056	0	1079	1079	0	1087	1087	0	1055	1055	0
50-0-0-1	743	743	0	729	729	0	692	692	0	740	740	0	731	731	0
50-0-0-2	725	725	0	713	713	0	718	718	0	707	707	0	710	710	0
50-0-0-3	689	689	0	681	681	0	664	664	0	673	673	0	662	662	0
50-0-3-1	875	875	0	880	880	0	907	907	0	873	873	0	848	848	0
50-0-3-2	899	899	0	911	911	0	900	900	0	919	919	0	900	900	0
50-0-3-3	882	882	0	877	877	0	909	909	0	877	877	0	901	901	0
50-2-0-1	883	883	0	886	886	0	887	887	0	876	876	0	887	887	0
50-2-0-2	701	701	0	700	700	0	715	715	0	692	692	0	688	688	0
50-2-0-3	812	812	0	826	826	0	817	817	0	812	812	0	823	823	0
50-2-3-1	942	942	0	948	948	0	929	929	0	929	929	0	950	950	0
50-2-3-2	1060	1060	0	1054	1054	0	1064	1064	0	1047	1047	0	1051	1051	0
50-2-3-3	1023	1023	0	1016	1016	0	1052	1052	0	1036	1036	0	1014	1014	0

Table B.19: Simulated Annealing (CPU intensive runs), raw results.

Problems	1			2			3			4			5		
30-0-0-1	460062	1062	765	442028	1028	735	415000	1000	690	414974	974	690	433010	1010	720
30-0-0-2	253085	1085	420	198963	963	330	253038	1038	420	271072	1072	450	226039	1039	375
30-0-0-3	109116	1116	180	127127	1127	210	109134	1134	180	82076	1076	135	145187	1187	240
30-0-3-1	226237	1237	375	271292	1292	450	289314	1314	480	289307	1307	480	289271	1271	480
30-0-3-2	334300	1300	555	280210	1210	465	334286	1286	555	307305	1305	510	307264	1264	510
30-0-3-3	586143	1143	975	604146	1146	1005	604186	1186	1005	604163	1163	1005	631204	1204	1050
30-2-0-1	559414	1414	930	496300	1300	825	451165	1165	750	487299	1299	810	505332	1332	840
30-2-0-2	468877	877	780	450864	864	750	441816	816	735	459887	887	765	477878	878	795
30-2-0-3	1332958	958	2220	1350853	853	2250	1350867	867	2250	1350850	850	2250	1341818	818	2235
30-2-3-1	1054135	1135	1755	1063170	1170	1770	1063148	1148	1770	1063192	1192	1770	1027048	1048	1710
30-2-3-2	703549	1549	1170	757412	1412	1260	712265	1265	1185	730560	1560	1215	793611	1611	1320
30-2-3-3	649141	1141	1080	640132	1132	1065	649118	1118	1080	658108	1108	1095	631079	1079	1050
40-0-0-1	1099	1099	0	1138	1138	0	1236	1236	0	1153	1153	0	1207	1207	0
40-0-0-2	1172	1172	0	1165	1165	0	1167	1167	0	1182	1182	0	1200	1200	0
40-0-0-3	1123	1123	0	1132	1132	0	1168	1168	0	1127	1127	0	1069	1069	0
40-0-3-1	1273	1273	0	1233	1233	0	1250	1250	0	1282	1282	0	1240	1240	0
40-0-3-2	1174	1174	0	1088	1088	0	1131	1131	0	1167	1167	0	1172	1172	0
40-0-3-3	1312	1312	0	1238	1238	0	1262	1262	0	1279	1279	0	1281	1281	0
40-2-0-1	334132	1132	555	352059	1059	585	289126	1126	480	316106	1106	525	352120	1120	585
40-2-0-2	1032	1032	0	989	989	0	1007	1007	0	1015	1015	0	1020	1020	0
40-2-0-3	1120	1120	0	1013	1013	0	1116	1116	0	1149	1149	0	1131	1131	0
40-2-3-1	1148	1148	0	1175	1175	0	1137	1137	0	1165	1165	0	1176	1176	0
40-2-3-2	1054	1054	0	1055	1055	0	1052	1052	0	1042	1042	0	1031	1031	0
40-2-3-3	1066	1066	0	1166	1166	0	1223	1223	0	1148	1148	0	1179	1179	0
50-0-0-1	1231	1231	0	1255	1255	0	1179	1179	0	1237	1237	0	1255	1255	0
50-0-0-2	1108	1108	0	1153	1153	0	1130	1130	0	1128	1128	0	1237	1237	0
50-0-0-3	1180	1180	0	1204	1204	0	1194	1194	0	1086	1086	0	1099	1099	0
50-0-3-1	1205	1205	0	1190	1190	0	1270	1270	0	1225	1225	0	1262	1262	0
50-0-3-2	1291	1291	0	1321	1321	0	1284	1284	0	1213	1213	0	1146	1146	0
50-0-3-3	1298	1298	0	1280	1280	0	1275	1275	0	1271	1271	0	1216	1216	0
50-2-0-1	1139	1139	0	1144	1144	0	1166	1166	0	1089	1089	0	1142	1142	0
50-2-0-2	982	982	0	1017	1017	0	1000	1000	0	986	986	0	1008	1008	0
50-2-0-3	1065	1065	0	1067	1067	0	1038	1038	0	991	991	0	1083	1083	0
50-2-3-1	1059	1059	0	1092	1092	0	1092	1092	0	1057	1057	0	1068	1068	0
50-2-3-2	1203	1203	0	1169	1169	0	1179	1179	0	1194	1194	0	1180	1180	0
50-2-3-3	1136	1136	0	1169	1169	0	1159	1159	0	1171	1171	0	1145	1145	0

Table B.20: Tabu Search (CPU intensive runs), raw results.