Incorporating Capacity Constraints and Least Cost Path Analysis into a Geographical Accessibility Model of General Practitioners

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ABSTRACT (EXTENDED)

Accessibility to General Practitioners is a social and economic issue that has many dimensions. This paper focuses on geographical accessibility and uses Geographical Information Systems to demonstrate three techniques that can be described as ratio, least cost path analysis (LCPA) and allocation methods. The ratio method is the most common and simply measures the population to GP ratio for a given area. The least cost path and allocation techniques rely on GIS network analysis and provide information on travel times and distances based on a private vehicle using public roads. The allocation method differs from least cost path analysis because it considers the number of GPs available and how many people a GP can service. This acts as a capacity constraint and the number of people serviced by a GP was set at 1400. Travel time and distance is calculated for every census enumeration district in New Zealand (approximately 38,000) and this enables population based accessibility statistics to be calculated. These include the average and total travel time if everybody visited a GP once and the population more than 30 minutes from a GP. There are significant regional differences in geographical accessibility in New Zealand and these differences are dependant on the method used to calculate accessibility. Table 1 compares GP accessibility for the different Territorial Local Authorities in New Zealand and also compares the three techniques used. These statistics are influenced by the underlying population distribution within a region and careful consideration is needed to determine which statistic best reflects geographical access. The use of a capacity constraint is important and is therefore the preferred approach. The population further than 30 minutes from a GP is an effective statistic for comparing the accessibility of different management regions. The Far North District has the highest population (9270) more than 30 minutes from a GP using the allocation method, which is nearly twice the next highest Territorial Local Authority (Southland District).

The GIS network analysis approached used in this study provides a data set that enable different population groups to be individually analyzed. Table 2 shows the population more than 30 minutes from a GP for 15 different population groups, -under 5 year olds, over 65 year olds, Maori, Pacific Islanders, Non Maori and Pacific Islanders, and each of the 10 deprivation index groups. These groups are not mutually exclusive. The network analysis was completed using the allocation method with a capacity constraint of 1400 people per GP. With Table 2 the TLAs are divided into three groups based on the population density of the TLA. Population density is expressed as population per square kilometer and is shown in table. This characterization of TLAs provides an additional insight into accessibility. With TLAs with low population density it is expected that it would be more difficult to have good accessibility to GPs compared to TLAs with high population densities. The results from this research are still being analyzed, however, a figure that is very apparent is the 5415 people in the Far North District that have the most deprived index score. Even though the Far North District has a population density in the mid range, it has the poorest accessibility, and many of these people with poor accessibility are relatively economically deprived.

Table 1: Comparison of Techniques

Territorial Local Authority	Total Population	Number of GPs	Population per GP	Average travel time based on LCPA (minutes)	Population more than 30 min from GP based on LCPA	Population more than 30 min from GP based on Allocation Analysis	Population more than 60 min from GP based on Allocation Analysis
Ashburton District	25446	21	1212	6.8	468	750	168
Auckland City	367725	442	832	1.7	537	537	135
Banks Peninsula District	7824	7	1118	9.2	705	705	0
Buller District	9651	22	439	10.8	954	954	87
Carterton District	6831	3	2277	7.0	78	435	21
Central Hawkes Bay District	12810	9	1423	12.9	1554	1671	720
Central Otago District	14463	16	904	8.5	993	1074	183
Christchurch City	316251	377	839	1.8	0	0	0
Clutha District	17187	18	955	11.3	1827	2592	39
Dunedin City	114297	128	893	3.8	621	723	66
Far North District	54612	51	1071	15.3	7734	9270	3405
Franklin District	51651	32	1614	9.0	1839	3702	498
Gisborne District	43962	37	1188	8.1	2802	4257	1617
Gore District	12492	12	1041	6.0	264	378	0
Grey District	12885	17	758	8.8	1281	1443	216
Hamilton City	114933	140	821	2.0	0	0	0
Hastings District	67413	56	1204	5.7	2541	3450	951
Hauraki District	16767	9	1863	6.2	93	2688	0
Horowhenua District	29799	19	1568	4.1	0	456	0
Hurunui District	9888	8	1236	14.6	1614	2550	72
Invercargill City	49842	46	1084	3.9	9	705	0
Kaikoura District	3468	5	694	10.1	258	258	93
Kaipara District	17451	15	1163	17.3	2559	4806	429
Kapiti Coast District	42438	52	816	3.6	0	0	0
Kawerau District	6969	7	996	2.7	0	0	0
Lower Hutt City	95439	76	1256	2.6	0	177	0
Mackenzie District	3735	4	934	17.8	897	948	405
Manawatu District	27510	19	1448	8.2	366	2766	627
Manukau City	283146	232	1220	2.4	1044	1137	0
Marlborough District	39561	33	1199	8.3	2283	3711	1311
Masterton District	22620	20	1131	6.4	1113	1173	381
Matamata-Piako District	29460	19	1551	6.7	0	2877	0
Napier City	53649	74	725	2.2	0	0	0
Nelson City	41544	44	944	3.3	48	48	0
New Plymouth District	66618	67	994	3.8	477	1368	249
North Shore City	184803	182	1015	2.2	0	0	0
Opotiki District	9171	7	1310	14.0	1458	1851	507
Otorohanga District	9300	5	1860	13.2	582	1065	45
Palmerston North City	72015	73	987	2.6	0	0	0
Papakura District	40647	45	903	2.5	0	0	0
Porirua City	47331	36	1315	2.8	0	0	0
Queenstown-Lakes District	17031	26	655	9.0	744	744	429
Rangitikei District	15087	11	1372	10.3	1008	1398	723
Rodney District	76209	58	1314	6.4	831	2799	144
Rotorua District	64470	57	1131	5.6	2724	4092	0
Ruapehu District	14292	10	1429	11.8	2061	2505	690
Selwyn District	27330	13	2102	7.7	321	3753	330
South Taranaki District	27537	27	1020	5.6	225	705	144
South Waikato District	23472	21	1118	5.8	18	33	0
South Wairarapa District	8754	6	1459	7.7	594	1413	753
Southland District	28737	20	1437	17.8	3636	5844	1170
Stratford District	8910	5	1782	8.8	519	1662	501
Tararua District	17853	12	1488	11.7	2073	2247	1278
Tasman District	41328	37	1117	8.7	2748	2916	564
Taupo District	31497	28	1125	7.8	1137	1140	63
Tauranga District	90891	122	745	2.4	0	0	0
Thames-Coromandel District	25179	32	787	9.0	1182	2145	174
Timaru District	41970	30	1399	4.2	60	1665	18
Upper Hutt City	36366	33	1102	4.3	0	177	0
Waikato District	39828	17	2343	8.8	867	4170	150
Waimakariri District	36870	22	1676	5.0	93	2151	114
Waimate District	7071	6	1179	11.1	381	933	54
Waipa District	40266	31	1299	6.3	156	531	0
Wairoa District	8919	14	637	17.9	2682	2745	699
Waitakere City	168717	134	1259	2.8	0	228	0
Waitaki District	20115	21	958	7.7	837	942	84
Waitomo District	9450	8	1181	14.9	1905	1911	390
Wanganui District	43302	39	1110	4.8	912	1038	348
Wellington City	163875	172	953	2.0	0	0	0
Western Bay of Plenty District	38205	21	1819	9.0	234	2289	0
Westland District	7782	8	973	21.7	1557	1557	477
Whakatane District	32805	24	1367	7.9	1314	2178	624
Whangarei District	68100	64	1064	7.1	3015	5592	402
New Zealand	3735822	3614	1034	4.6	70833	122028	22548

Table 2: Population more than 30 minutes from a GP by different population groups.

Territorial Local Aurhority	Population Density pop/km^2	Under 5 years	Over 65 years	Maori	Pacific Islander	Non Maori or Pacific Islander	Dep 1	Dep 2	Dep 3	Dep 4	Dep 5	Dep 6	Dep 7	Dep 8	Dep 9	Dep 10
NORTH SHORE CITY	1405	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HAMILTON CITY	1220	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHRISTCHURCH CITY	697	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUCKLAND CITY	583	30	36	126	12	534	0	0	0	0	0	249	0	0	0	0
WELLINGTON CITY	564	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TAURANGA DISTRICT	537	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NAPIER CITY	513	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WAITAKERE CITY	455	12	39	30	6	207	0	0	0	0	108	0	135	0	0	0
MANUKAU CITY	412	60	168	165	21	942	9	36	282	168	0	267	0	366	0	0
PAPAKURA DISTRICT	338	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KAWERAU DISTRICT	316	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PORIRUA CITY	257	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LOWER HUTT CITY	250	15	9	21	0	153	0	0	0	0	174	0	0	0	0	0
PALMERSTON NORTH CITY	216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INVERCARGILL CITY	101	36	99	300	12	387	0	9	0	0	261	0	138	57	126	108
NELSON CITY	95	0	3	3	0	42	0	0	45	0	0	0	0	0	0	0
UPPER HUTT CITY	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KAPITI COAST DISTRICT	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DUNEDIN CITY	35	57	66	63	6	633	0	90	126	42	42	84	216	102	0	0
RODNEY DISTRICT	31	213	168	333	54	2544	18	69	111	1443	636	324	138	0	0	192
NEW PLYMOUTH DISTRICT	30	114	105	159	3	1197	0	93	291	207	216	258	177	117	0	0
HOROWHENUA DISTRICT	28	18	114	87	3	357	0	0	0	0	0	0	0	0	162	285
WAIPA DISTRICT	27	45	39	30	3	498	195	282	0	0	54	0	0	0	0	0
ROTORUA DISTRICT	25	369	225	972	66	3315	300	501	870	537	783	327	516	165	228	126
Subtotal	8258	969	1071	2289	186	10809	522	1080	1725	2397	2274	1509	1320	807	516	711
Sub-mean	344	40	45	95	8	450	22	45	72	100	95	63	55	34	22	30
WHANGAREI DISTRICT	24	432	552	1206	90	4353	0	69	84	1377	1179	621	369	447	609	894
FRANKLIN DISTRICT	24	276	411	732	60	3156	0	336	303	411	756	765	327	354	0	696
WANGANUI DISTRICT	18	69	78	273	15	744	0	135	0	0	222	327	0	0	207	141
WESTERN BAY OF PLENTY	18	183	141	192	12	2214	0	123	1005	252	570	408	0	60	0	0
MATAMATA-PIAKO DISTRICT	17	234	189	300	21	2553	51	357	276	843	603	429	189	126	0	0
WAIMAKARIRI DISTRICT	16	135	153	63	0	2187	441	975	513	303	18	0	0	0	0	0
TIMARU DISTRICT	15	108	129	51	3	1593	795	429	276	0	108	0	0	39	0	0
HAURAKI DISTRICT	14	186	300	333	51	2340	114	81	285	429	0	420	165	723	507	0
HASTINGS DISTRICT	13	306	198	501	24	3042	495	534	291	510	768	0	432	537	0	0
SOUTH WAIKATO DISTRICT	13	3	3	12	0	21	0	0	0	15	0	18	0	0	0	0
WAIKATO DISTRICT	12	348	312	651	51	3477	0	648	459	732	792	978	297	138	117	18
THAMES-COROMANDEL	12	138	267	156	15	2529	0	0	456	204	177	417	774	123	501	0
MANAWATU DISTRICT	10	216	195	237	18	2610	414	603	114	492	807	303	0	117	15	0
MASTERTON DISTRICT	10	78	90	135	21	1020	0	147	258	351	156	81	183	0	0	0
GORE DISTRICT	10	33	21	12	3	348	174	48	141	0	0	0	0	0	0	0
SOUTH TARANAKI DISTRICT	8	51	66	81	3	594	0	21	63	0	267	15	312	0	0	0
FAR NORTH DISTRICT	8	720	1002	4350	222	4785	0	0	0	0	0	156	807	1107	1872	5415
WHAKATANE DISTRICT	7	207	150	1347	36	792	0	0	0	210	0	243	204	57	423	1038
BANKS PENINSULA DISTRICT	7	48	84	69	9	642	0	0	33	201	0	486	0	0	0	0
CARTERTON DISTRICT	6	21	33	18	0	465	177	66	156	84	0	0	0	0	0	0
KAIPARA DISTRICT	6	327	492	915	78	3966	0	0	57	693	558	1869	489	528	429	336
GISBORNE DISTRICT	5	408	252	1788	21	2304	297	369	252	390	408	570	465	129	387	846
TAUPO DISTRICT	5	102	48	246	12	1038	111	201	0	234	87	0	282	117	258	0
OTOROHANGA DISTRICT	5	102	66	204	3	825	0	120	225	324	0	0	177	81	105	0
Subtotal	281	4731	5232	13872	768	47598	3069	5262	5247	8055	7476	8106	5472	4683	5430	9384
Sub-mean	12	197	218	578	32	1983	128	219	219	336	312	338	228	195	226	391
SELWYN DISTRICT	4	267	324	177	9	3702	198	1110	552	1296	165	567	0	0	0	0
STRATFORD DISTRICT	4	123	99	84	6	1548	0	549	165	444	258	129	72	21	0	0
TARARUA DISTRICT	4	195	114	276	12	1947	66	213	588	477	492	99	141	159	0	0
ASHBURTON DISTRICT	4	84	45	15	6	744	249	273	126	0	117	0	0	0	0	0
CENTRAL HAWKE'S BAY	4	111	114	312	21	1371	147	192	21	891	0	72	183	0	198	0
GREY DISTRICT	4	132	126	105	12	1347	0	48	225	15	438	135	375	228	0	0
SOUTH WAIRARAPA DISTRICT	4	108	117	147	6	1362	198	237	348	147	120	327	0	138	0	0
RANGITIKEI DISTRICT	3	132	81	174	0	1263	0	657	159	87	279	138	117	0	0	0
MARLBOROUGH DISTRICT	3	210	360	285	24	3855	288	117	570	300	873	576	1095	132	132	0
OPOTIKI DISTRICT	3	123	225	1152	24	753	0	0	27	324	0	0	0	0	207	1371
TASMAN DISTRICT	3	231	210	225	18	2772	0	294	0	441	873	174	843	132	258	0
WAITAKI DISTRICT	3	63	75	33	0	1017	108	276	108	300	219	0	0	39	0	0
WAITOMO DISTRICT	3	159	150	723	24	1191	45	51	174	63	318	114	171	348	552	102
CLUTHA DISTRICT	3	213	171	111	3	2553	837	780	315	201	186	348	0	0	0	0
RUAPEHU DISTRICT	2	177	192	609	30	2178	0	0	570	90	384	378	870	192	84	249
WAIROA DISTRICT	2	225	222	1515	42	1347	0	0	0	27	219	399	360	366	531	1002
QUEENSTOWN-LAKES	2	66	33	42	3	933	141	117	177	0	0	408	135	0	0	0
WAIMATE DISTRICT	2	63	48	24	0	894	228	249	258	183	0	0	0	0	0	0
KAIKOURA DISTRICT	2	18	21	39	0	201	0	0	21	0	0	219	0	0	0	0
CENTRAL OTAGO DISTRICT	2	66	84	48	3	1020	219	27	405	294	93	0	33	0	0	0
HURUNUI DISTRICT	1	198	288	120	6	3186	0	252	630	504	306	504	1116	0	0	0
BULLER DISTRICT	1	75	84	93	3	984	0	0	0	45	174	42	258	96	84	381
SOUTHLAND DISTRICT	1	450	444	504	21	6099	1500	2037	768	267	252	357	327	363	528	192
WESTLAND DISTRICT	1	96	123	93	3	1791	156	201	138	690	150	0	456	96	0	0
MACKENZIE DISTRICT	1	51	66	51	3	1218	0	330	318	246	378	0	0	0	0	0
Subtotal	64	3636	3816	6957	279	45276	4380	8010	6663	7332	6294	4986	6552	2310	2574	3297
Sub-mean	3	145	153	278	11	1811	175	320	267	293	252	199	262	92	103	132
Total	8603	9336	10119	23118	1233	103683	7971	14352	13635	17784	16044	14601	13344	7800	8520	13392
Mean	118	128	139	317	17	1420	109	197	187	244	220	200	183	107	117	183

This research has demonstrated the importance of GIS based population accessibility models. The data generated from these models provide new information that was previously impractical to generate manually. Research on improving these models is ongoing. This network analysis is dependant on a road network that incorporates travel time estimates. Information on road characteristics, including a sinuosity index, was used to calibrate the road travel times. These travel times were demonstrated to be within 8 percent of the New Zealand Automobile Association travel time estimates. The sinuosity index generated is dependant on the length of road segment used. The use of fractals may provide an alternative to sinuosity and these may be less dependant of road segment length. Another aspect of the model that can be improved is the use of centroids for large enumeration districts in rural areas. The center of an enumeration district may not accurately reflect where the population is within a large district. An alternative to centroids could be the use of address points. The LandOnLine project in New Zealand provides a point layer of every mail address. The location of these address points within an enumeration district could be used generate a point that accurately represents the population location with a district.

***Keywords and phrases*:** health accessibility, general practitioners, GIS, least cost path analysis

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