Quick Review of TSP Algorithms

- ► Brute force: Examine all (N − 1)! Hamilton circuits individually; choose the cheapest one.
- Finds the optimal answer but is very inefficient.
 - Nearest-Neighbor Algorithm (NNA): Pick a reference vertex. At each step, walk to the nearest vertex not already visited.
 - Repetitive Nearest-Neighbor Algorithm (RNNA): Perform the NNA from every possible reference vertex, obtaining N different Hamilton circuits. Choose the cheapest one.

The **Cheapest-Link Algorithm (CLA)** is a bit different.

Instead of starting at a reference vertex and moving to the nearest neighbor at each step, we "start in the middle."

That is, if there is a cheap edge that you know you will want to use eventually — make sure you use it!

At each stage of the algorithm, pick the cheapest edge available, regardless of what its endpoints are.

Of course, all the edges you pick have to come together to form a circuit.

Find the cheapest edge that you haven't already added.

- Find the cheapest edge that you haven't already added.
- Add it to the list of edges to use.

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- Keep doing this until you have a Hamilton circuit.
- Make sure you add exactly two edges at each vertex. (In other words, don't put a third edge at a vertex, and don't close the circuit too early.)

Here is an example of designing a tour of Australia using the Cheapest-Link Algorithm.

(Warning: The figure is not quite to scale!)



Start by finding the shortest edge (Sydney-Canberra).



Now find the next shortest edge (Perth-Albany).



And the next shortest (Alice Springs-Uluru)...



and the next shortest (Hobart-Melbourne)...



and the next shortest (Canberra-Melbourne).



The next shortest edge is actually Adelaide–Melbourne, but we can't use it because Melbourne already has two edges.



So instead we include the next shortest edge (Cairns-Mackay).















The edges we add get longer and longer.







The last edge is very long indeed...



... but finally the circuit is complete.

Here is the same example, but with the links shown in a spreadsheet rather than pictorially.

(This way we don't have to worry about the figure not being to scale!)

At each stage, we look for the smallest number we haven't yet used (always being careful not to draw three edges to any vertex, or to close the circuit prematurely).

The distance table

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4	Albany	AL	2673		3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	409	3970	3633		
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11	Hobart	HO	1001	3674	2534	1944	3636	3251	918	4023		4220	2682	609	3075	3782	1142	2579		
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Step 1: Add the cheapest link: Sydney-Canberra

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Step 2: Add the next cheapest link: Albany-Perth

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Step 3: Add the next cheapest link: Alice Spings-Uluru

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Step 4: Add the next cheapest link: Hobart-Melbourne

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			Distan	ice (km)														
			AD	AL	AS	BT	BM	CS	CN	DA	HO	KU	MK	ML	MI	PE	SY	UL	
	Adelaide	AD		2673	1533	2045	2483	3352	1196	3022	1001	3219	2783	731	2742	2781	1412	1578	
	Albany	AL	2673		3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	409	3970	3633	
	Alice Springs	AS	1533	3588		3038	2483	2457	3706	1489	2534	1686	2505	2264	1209	3696	3830	443	
	Brisbane	BT	2045	4349	3038		3317	1716	1261	3463	1944	3660	976	1674	1829	4457	1001	3254	
	Broome	BM	2483	1943	2483	3317		2496	3275	1803	3636	1045	2840	3124	1834	2389	3373	1223	
	Cairns	CS	3352	5656	2457	1716	2496		2568	2882	3251	3079	740	2981	1248	5764	2495	2900	
	Canberra	CN	1196	3846	3706	1261	3275	2568		4195	918	4392	1999	648	2561	3954	286	2751	
)	Darwin	DA	3022	4614	1489	3463	1803	2882	4195		4023	827	2930	3753	1634	4205	4034	1932	
ı	Hobart	HO	1001	3674	2534	1944	3636	3251	918	4023		4220	2682	609	3075	3782	1142	2579	
	Kununurra	KU	3219	3787	1686	3660	1045	3079	4392	827	4220		3127	3950	1831	3378	4516	2129	
2	Mackay	MK	2783	5087	2505	976	2840	740	1999	2930	2682	3127		2412	1296	5195	1926	2948	
	Melbourne	ML	731	3404	2264	1674	3124	2981	648	3753	609	3950	2412		2805	3512	872	2309	
;	Mount Isa	MI	2742	5106	1209	1829	1834	1248	2561	1634	3075	1831	1296	2805		4905	2400	1652	
	Perth	PF	2781	409	3696	4457	2389	5764	3954	4205	3782	3378	5195	3512	4905		4078	3741	
7	Sydney	SY	1412	3970	3830	1001	3373	2495	286	4034	1142	4516	1926	872	2400	4078		2875	
2	Uluru	U	1578	3633	443	3254	1223	2900	2751	1932	2579	2129	2948	2309	1652	3741	2875	2010	
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Step 5: Add the cheapest link: Canberra-Melbourne

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			AD	AL	AS	BT	BM	CS	CN	DA	HO	KU	MK	ML	MI	PE	SY	UL	
	Adelaide	AD		2673	1533	2045	2483	3352	1196	3022	1001	3219	2783	731	2742	2781	1412	1578	
	Albany	AL	2673		3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	409	3970	3633	
	Alice Springs	AS	1533	3588		3038	2483	2457	3706	1489	2534	1686	2505	2264	1209	3696	3830	443	
	Brisbane	BT	2045	4349	3038		3317	1716	1261	3463	1944	3660	976	1674	1829	4457	1001	3254	
	Broome	BM	2483	1943	2483	3317		2496	3275	1803	3636	1045	2840	3124	1834	2389	3373	1223	
	Cairns	CS	3352	5656	2457	1716	2496		2568	2882	3251	3079	740	2981	1248	5764	2495	2900	
	Canberra	CN	1196	3846	3706	1261	3275	2568		4195	918	4392	1999	648	2561	3954	286	2751	
1	Darwin	DA	3022	4614	1489	3463	1803	2882	4195		4023	827	2930	3753	1634	4205	4034	1932	
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>	Kununurra	KU	3219	3787	1686	3660	1045	3079	4392	827	4220		3127	3950	1831	3378	4516	2129	
	Mackay	MK	2783	5087	2505	976	2840	740	1999	2930	2682	3127		2412	1296	5195	1926	2948	
	Melbourne	ML	731	3404	2264	1674	3124	2981	648	3753	609	3950	2412		2805	3512	872	2309	
	Mount Isa	MI	2742	5106	1209	1829	1834	1248	2561	1634	3075	1831	1296	2805		4905	2400	1652	
	Perth	PF	2781	409	3696	4457	2389	5764	3954	4205	3782	3378	5195	3512	4905		4078	3741	
7	Sydney	SY	1412	3970	3830	1001	3373	2495	286	4034	1142	4516	1926	872	2400	4078		2875	
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CN and ML both have two edges, so we are done with them

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3	Adelaide	AD		2673	1533	2045	2483	3352	1196	3022	1001	3219	2783	731	2742	2781	1412	1578		
4	Albany	AL	2673		3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	409	3970	3633		
5	Alice Springs	AS	1533	3588		3038	2483	2457	3706	1489	2534	1686	2505	2264	1209	3696	3830	443		
6	Brisbane	BT	2045	4349	3038		3317	1716	1261	3463	1944	3660	976	1674	1829	4457	1001	3254		
7	Broome	BM	2483	1943	2483	3317		2496	3275	1803	3636	1045	2840	3124	1834	2389	3373	1223		
8	Cairns	CS	3352	5656	2457	1716	2496		2568	2882	3251	3079	740	2981	1248	5764	2495	2900		
9	Canberra	CN	1196	3846	3706	1261	3275	2568		4195	918	4392	1999	648	2561	3954		2751		
10	Darwin	DA	3022	4614	1489	3463	1803	2882	4195		4023	827	2930	3753	1634	4205	4034	1932		
11	Hobart	HO	1001	3674	2534	1944	3636	3251	918	4023		4220	2682	609	3075	3782	1142	2579		
12	Kununurra	KU	3219	3787	1686	3660	1045	3079	4392	827	4220		3127		1831	3378	4516	2129		
13	Mackay	MK	2783	5087	2505	976	2840	740	1999	2930	2682	3127		2412	1296	5195	1926	2948		
14	Melbourne	ML	731	3404	2264	1674	3124	2981	648	3753	609		2412		2805	3512	872	2309		
15	Mount Isa	MI	2742	5106	1209	1829	1834	1248	2561	1634	3075	1831	1296	2805		4905	2400	1652		
16	Perth	PE	2781	409	3696	4457	2389	5764	3954	4205	3782	3378	5195	3512	4905		4078	3741		
17	Sydney	SY	1412	3970	3830	1001	3373	2495	286	4034	1142	4516	1926	872	2400	4078		2875		
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	Brisbane	BI	2045	4349	3038	0047	3317	1/16		3463	1944	3660	976	1674	1829	4457	1001	3254		
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2	Kununurra	KU	3219	3787	1686	3660	1045	3079	4392	827	4220		3127	3950	1831	3378	4516	2129		
3	Mackay	MK	2783	5087	2505	976	2840	740	1999	2930	2682	3127		2412	1296	5195	1926	2948		
1	Melbourne	ML	731	3404	2264	1674	3124	2981	648	3753	609	3950	2412		2805	3512	872	2309		
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	Albany	AL	20/3	0500	3000	4349	1943	0000	0700	4014	3074	3/0/	0505	0404	5106	409	3970	3033		
	Alice Springs	AS	1533	3588	0000	3038	2483	2457	3706	1489	2534	1686	2505	2204	1209	3696	3830	443		
	Brisbane	BI	2045	4349	3038		3317	1/16	1201	3463	1944	3660	976	1674	1829	4457	1001	3254		
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	Alice Springs	AS	1533	3588		3038	2483	2457	3706	1489	2534	1686	2505	2264	1209	3696	3830	443		
	Brisbane	BT	2045	4349	3038		3317	1716	1261	3463	1944	3660	976	1674	1829	4457	1001	3254		
	Broome	BM	2483	1943	2483	3317		2496	3275	1803	3636	1045	2840	3124	1834	2389	3373	1223		
	Cairns	CS	3352	5656	2457	1716	2496		2568	2882	3251	3079	740	2981	1248	5764	2495	2900		
	Canberra	CN	1196	3846	3706	1261	3275	2568		4195	918	4392	1999	648	2561	3954	286	2751		
0	Darwin	DA	3022	4614	1489	3463	1803	2882	4195		4023	827	2930	3753	1634	4205	4034	1932		
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	Albany	AL	2673	2010	3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	409	3970	3633		
	Alice Springs	AS	1533	3588		3038	2483	2457	3706	1489	2534	1686	2505	2264	1209	3696	3830	443		
	Brisbane	BT	2045	4349	3038		3317	1716	1261	3463	1944	3660	976	1674	1829	4457	1001	3254		
	Broome	BM	2483	1943	2483	3317		2496	3275	1803	3636	1045	2840	3124	1834	2389	3373	1223		
	Cairns	CS	3352	5656	2457	1716	2496		2568	2882	3251	3079	740	2981	1248	5764	2495	2900		
	Canberra	CN	1196	3846	3706	1261	3275	2568		4195	918	4392	1999	648	2561	3954	286	2751		
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2	Kununurra	KU	3219	3787	1686	3660	1045	3079	4392	827	4220		3127	3950	1831	3378	4516	2129		
3	Mackay	MK	2783	5087	2505	976	2840	740	1999	2930	2682	3127		2412	1296	5195	1926	2948		
4	Melbourne	ML	731	3404	2264	1674	3124	2981	648	3753	609	3950	2412		2805	3512	872	2309		
5	Mount Isa	MI	2742	5106	1209	1829	1834	1248	2561	1634	3075	1831	1296	2805		4905	2400	1652		
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7	Sydney	SY	1412	3970	3830	1001	3373	2495	286	4034	1142	4516	1926	872	2400	4078		2875		
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n H	ome Layout Ta	ibles	Charts	SmartArt	Formulas	Data	Review													~
4	A	B	C	D	E	F	G	Н	1	J	K	L	M	N	0	P	Q	R	S	
			Distar	ice (km)															
			AD	AL	AS	BT	BM	CS	CN	DA	HO	KU	MK	ML	MI	PE	SY	UL		
	Adelaide	AD		2673	1533	2045	2483	3352	1196	3022		3219	2783	731	2742	2781	1412	1578		
	Albany	AL	2673		3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	409	3970	3633		
	Alice Springs	AS	1533	3588		3038	2483	2457	3706	1489	2534	1686	2505	2264		3696	3830	443		
	Brisbane	BT	2045	4349	3038		3317	1716	1261	3463	1944	3660		1674	1829	4457	1001	3254		
	Broome	BM	2483	1943	2483	3317		2496	3275	1803	3636		2840	3124	1834	2389	3373	1223		
	Cairns	CS	3352	5656	2457	1716	2496		2568		3251	3079		2981	1248	5764	2495	2900		
	Canberra	CN	1196	3846	3706	1261	3275	2568		4195	918	4392	1999	648	2561	3954	286	2751		
D	Darwin	DA	3022	4614	1489	3463	1803	2882	4195		4023			3753	1634	4205	4034	1932		
1	Hobart	HO	1001	3674	2534	1944	3636	3251	918	4023		4220		609	3075	3782	1142	2579		
2	Kununurra	KU	3219	3787	1686	3660	1045	3079	4392	827	4220		3127	3950	1831	3378	4516	2129		
3	Mackay	MK	2783	5087	2505	976	2840	740	1999	2930	2682	3127		2412	1296	5195	1926	2948		
	Melbourne	ML	731	3404	2264	1674	3124	2981	648	3753	609		2412		2805	3512	872	2309		
5	Mount Isa	MI	2742	5106	1209	1829	1834	1248	2561	1634	3075	1831	1296	2805		4905	2400	1652		
5	Perth	PE	2781	409	3696	4457	2389	5764	3954	4205	3782	3378	5195	3512	4905		4078	3741		
7	Sydney	SY	1412	3970	3830	1001	3373	2495	286	4034	1142	4516	1926	872	2400	4078		2875		
8	Úluru		1578	3633	443	3254	1223	2900	2751	1932	2579	2129	2948	2309	1652	3741	2875			
9																				
D		DA +	+ KU ←	BM ↔	UL ↔ A	S ↔ M	I↔CS	↔ MK	↔ BT ·	→ SY +	+ CN ↔	ML ↔	HO ↔ /	٨D			AL ↔ I	PE		
1																				
88	In a h h J Step 4	Step 5	Step Sb 2	step 6 🖌 Step	7 J Step 8 J	Step 9 St	ep 14 / 1 =									_	_	_	_	_

Next-to-last step: add AD-AL

					formation and												(di ili pricet		
1	ame Layout Ta	R	Charts	D	F	F	G	н			K		M	N	0	P	0	R	s	
Ē			Distan	nce (km)		u			,	N.	-			0		~			
			AD	AL	AS	BT	BM	CS	CN	DA	НО	KU	MK	ML	MI	PE	SY	UL		
	Adelaide	AD		2673	1533	2045	2483	3352	1196	3022	1001	3219	2783	731	2742	2781	1412	1578		
	Albany	AL	2673		3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	409	3970	3633		
	Alice Springs	AS	1533	3588		3038	2483	2457	3706	1489	2534	1686	2505	2264	1209	3696	3830	443		
	Brisbane	BT	2045	4349	3038		3317	1716	1261	3463	1944	3660	976	1674	1829	4457	1001	3254		
	Broome	BM	2483	1943	2483	3317		2496	3275	1803	3636	1045	2840	3124	1834	2389	3373	1223		
	Cairns	CS	3352	5656	2457	1716	2496		2568	2882	3251	3079	740	2981	1248	5764	2495	2900		
	Canberra	CN	1196	3846	3706	1261	3275	2568		4195	918	4392	1999	648	2561	3954	286	2751		
	Darwin	DA	3022	4614	1489	3463	1803	2882	4195		4023	827	2930	3753	1634	4205	4034	1932		
	Hobart	HO	1001	3674	2534	1944	3636	3251	918	4023		4220	2682	609	3075	3782	1142	2579		
	Kununurra	KU	3219	3787	1686	3660	1045	3079	4392	827	4220		3127	3950	1831	3378	4516	2129		
	Mackay	MK	2783	5087	2505	976	2840	740	1999	2930	2682	3127		2412	1296	5195	1926	2948		
	Melbourne	ML	731	3404	2264	1674	3124	2981	648	3753	609	3950	2412		2805	3512	872	2309		
	Mount Isa	MI	2742	5106	1209	1829	1834	1248	2561	1634	3075	1831	1296	2805		4905	2400	1652		
	Perth	PE	2781	409	3696	4457	2389	5764	3954	4205	3782	3378	5195	3512	4905		4078	3741		
	Sydney	SY	1412	3970	3830	1001	3373	2495	286	4034	1142	4516	1926	872	2400	4078		2875		
	Uluru	UL	1578	3633	443	3254	1223	2900	2751	1932	2579	2129	2948	2309	1652	3741	2875			
			DA ↔	KU ↔ E	BM ↔ U	L ↔ AS	i ↔ MI ·	→ CS +	→ MK +	BT ↔	SY ↔ I		/L ↔ H	O ↔ AD	AL ↔ AL	↔ PE				

Last step: close the circuit

	>⊟≡ □ �	466			N. 30.	N. C	150% *										(Qr (Sear	ch in Sheet	-
*	Home Layout Ta	bles	Charts	SmartArt	Formulas	Data	Review				K		м	M	0	D	0	n	6
i	A	D	Dietan	co (km)	E	r	u	п		J	ĸ	L	M	IN	0	r	Q	ĸ	3
1			AD		46	DT	DM	20	CN	DA	но	KU	MK	MI	MI	DE	ev	1.0	
	Adelaide		~	2673	1533	2045	2483	3352	1106	3022	1001	3219	2783	731	2742	2781	1412	1578	
	Albany		2673	2010	3588	4349	1943	5656	3846	4614	3674	3787	5087	3404	5106	400	3070	3633	
	Alice Springe	AS	1533	3588	0000	3038	2483	2457	3706	1480	2534	1686	2505	2264	1200	3606	3830	443	
	Briebane	BT	2045	4340	3038	5050	3317	1716	1261	3463	1044	3660	076	1674	1820	4457	1001	3254	
	Broome	BM	2483	10/3	2483	3317	3317	2406	3275	1803	3636	1045	2840	3124	1834	2380	3373	1223	
	Cairne	CS	3352	5656	2465	1716	2406	2430	2568	2882	3251	3070	740	2081	1248	5764	2405	2000	
	Canhorra	CN	1106	3946	3706	1261	3275	2569	2000	4105	019	4302	1000	649	2561	3054	2485	2751	
	Danwin	DA	2022	4614	1490	2462	1903	2000	4105	4100	4022	927	2020	3753	1634	4205	4034	1032	
,	Hobort		1001	2674	2524	1044	2626	2002	019	4022	4023	4220	2800	600	2075	2792	1142	2670	
	Kupupurro	KU	2210	3797	1696	2660	1045	2070	4202	927	4220	4220	2107	2050	1921	2279	4516	2120	
2	Maakay	MIC	3213	5097	2505	076	2940	740	4092	2020	9220	2127	3127	2412	1206	5105	4010	2049	
2	Molbourpo	MI	721	2404	2000	1674	2040	2091	649	2930	2002	2050	2412	2412	2905	2612	970	2340	
*	Mount loo	MAL	2742	5404	1204	1920	1024	1049	2561	1624	2075	1021	1206	2005	2005	4005	2400	1652	
0	Dorth	DE	2791	400	2606	1029	1034	5764	2001	4205	30/5	2270	1290	2005	4005	4905	2400	2744	
0	Ferth	PE	2/01	409	3090	440/	2009	3/04	3954	4024	1142	33/8	1006	070	4905	4079	40/8	0075	
1	Syuney	31	1412	3870	3030	2054	33/3	2495	200	4034	1142	4010	1920	0/2	2400	40/8	2075	20/5	
8	oidru	UL	13/8	3033	443	3254	1223	2900	2/51	1932	25/9	2129	2948	2309	1052	5/41	20/5		
9			DA						MIC	DT	CV .					DE	DA		
D			$DA \rightarrow$	$KU \rightarrow E$	im → U	$L \rightarrow AS$	→ MI -	→ CS -	→ MK –	• BI →	SY → I	$GIN \rightarrow N$	$\Pi \rightarrow H_{i}$	$J \rightarrow AL$	$\rightarrow AL$	→ PE -	→ DA		

Here is the output of the Cheapest-Link Algorithm.



It is not optimal since it involves crossings...



... this route is an improvement.



But it is unclear whether the new route is optimal.



For example, maybe this route is even better.



Randomly chosen Hamilton circuit:40Hamilton circuit using NNA/Sydney:22Hamilton circuit using RNNA:14Hamilton circuit using CLA:18

40,680 km 21,049 km **18,459 km** 18,543 km

So CLA did not find an optimal circuit. But it is a reasonable method that might perform better in a different example.

Might there be an even better Hamilton circuit? Can we find it without having to use brute force?

There is no <u>known</u> algorithm to solve the TSP that is both optimal and efficient.

- Brute-force is optimal but not efficient.
- NNA, RNNA, and CLA are efficient but not optimal.
- Maybe no optimal, efficient algorithm exists... or maybe it's out there but no one has found it yet. We don't know!