ALMA Memo 280
Antenna Transport Times and Reconfiguration Schedule

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Abstract

Antenna transport times and resulting array reconfiguration times are estimated from current specifications and an array configuration schedule is proposed. To support a 10 km configuration and antenna assembly in San Pedro, the ALMA should have at least four antenna transporters so no less than three are active during reconfiguration.

Introduction

Several earlier Memos (147, 199, 265, 274, & 277) have debated array reconfiguration strategy. In these discussions, the antenna transport time has generally been taken as constant, independent of the configuration size. This is unrealistic, however, because of the large range of sizes, which span a factor of 67 in the current concept, 150 m to 10 km. Hence different factors determine the reconfiguration times for small and large configurations.

Based on the transporter and antenna specifications and rough characteristics of the configurations, I estimate antenna transport times for the the different configurations. Although generally similar to previous estimates, these new estimates are more pessimistic for the extended configurations and more optimistic for compact configurations.

Regardless of the reconfiguration strategy, continuous or step, the overall time necessary to redeploy between given configurations depends only on the number of transporters in simultaneous operation, the antenna transport times, and the length of the work day. Although a crucial question for configuration design and array operations, the array's productivity during reconfiguration is not directly addressed by this memo.

Because it will take significantly longer to move antennae into the largest, 10 km configuration than into the smaller configurations, I suggest that configuration be deployed less often. For example, in an 18 month cycle where the array is configured every two months, the 10 km configuration is used once each cycle and the smaller ones twice. With a 10 km configuration and antenna assembly in San Pedro, the ALMA should have at least four transporters, so no less than three are active during reconfiguration.

Transport Times

The relevant specifications (Table 1) are the pickup and dropoff times, the transporter speeds, the maximum wind speed during transport, and 64 antennae to be deployed in five configurations with diameters of 150 m (40% filled), 450 m, 1.1 km, 3 km, and 10 km. So far, no specification has been placed on transporter acceleration. Note the Project Book gives more relaxed specifications for antenna pickup and dropoff, 20 and 30 min, respectively, than the antenna RFP.

Within and between the small configurations, 150 m–1.1 km, the transport times are largely independent of the configuration size. At full speed, a loaded transporter could circumnavigate a 1.1 km diameter circle in about 20 min. For these small configurations, typical transport distances will be smaller than this, so low speed maneuvering and accelerations are likely more significant than full speed travel. Furthermore, there must be some allowance for unforseen activity and (human) inefficiency, i. e., overhead and contingency. Hence I estimate it should be possible to move an antenna in an hour, 15 min each for pickup and dropoff plus 15 min of low speed maneuvering with the transporter plus 15 min overhead (Table 2).

For the larger configurations, on the other hand, the travel time dominates. As a first approximation, I assume the stations are uniformly distributed along a road about the circumference of a circle. Then starting from a compact configuration tangent to the larger configuration, the mean travel distance is one quarter of the circumference and the longest move is twice that. Because the road will not be a perfect circle, but will detour to accomodate the terrain, these are lower bounds to the travel distances. Furthermore, the vertical road profile will not be known prior to detailed site layout, so I assume the average transporter speed is 7.5 km h^{-1} (15 km h^{-1} unloaded), including accelerations, gradients, and detours.

Then it would take about 1.25 h to move the average antenna to the 3 km configuration (pickup, dropoff, and overhead as above plus 20 min transport plus 10 min transporter return) and 1.75 h for the longest move, which is half the circumference (overheads plus 40 min transport plus 20 min return). For the 10 km configuration, the average move will be 2.5 h (overheads plus 65 min transport plus 35 min return) and the longest move will be 3.75 h (overheads plus 2 h transport plus 1 h return).

There has been some discussion of extending the array with a 20 km configuration. In this case, the average move will be 4 h (overheads plus 130 min transport plus 65 min return) and the longest move will be 7 h (overheads plus 4.2 h transport plus 2.1 h return).

Travel times would be reduced if the roads were radial, rather than circumferential. Futhermore, it is probably quicker to go between the 3 km to 10 km configurations than between the 150 m and 10 km configurations. These refinements seem unlikely, however, to cause dramatic changes in the travel times.

Reconfiguration Times

Regardless of the reconfiguration strategy, continuous or step, the overall time necessary to move antennas between given configurations depends only on the antenna transport times (Table 2), the number of transporters operating, and the length of the work day.

Under a "Turno" system, daily work shifts might be 10-11 h (Project Book, chapter 18), but the travel time by road from San Pedro to Chajnantor is about 1.25 h (about 45 km) each way. Moreover, meal breaks, etc., must be allowed. Hence, the effective work shift at the array site will probably not exceed 7-8 h. If operations are reduced on holidays and weekends, reconfigurations would be lengthened.

Adverse weather may complicate reconfiguration. At Chajnantor, the wind is strongest during the afternoon and during the winter months, when the median afternoon wind speed (Figure 1) approaches the limit for antenna transport (16 m s^{-1}). Moreover, winter snowstorms might preclude antenna transport until roads are plowed, a further delay. At Chajnantor, 23° S latitude, daylight varies from 10.5 h in winter to 13.5 h in summer. Nighttime antenna movement is possible in principle, but would require adquate artificial illumination that may conflict with other future facilities, i. e., optical telescopes. If antennas are not moved at night and cannot be moved during the afternoon because of the wind, the effective working day will be shortened and overall reconfiguration times will be proportionately longer.

For safety reasons, if nothing else, a transport crew should have at least three people, one to operate the transporter (driver) and two to guide the driver, connect cables, etc. (flaggers). If several transporters operate simultaneously, the number of people could be reduced by having two flaggers for antenna pickup, two flaggers for dropoff, and one driver per transporter, rather than a complete crew for each transporter. This arrangement might be especially suitable for moves between small configurations, when the pickup and dropoff times are comparable to the transport times.

The time required for post-reconfiguraton pointing, baseline determination, etc., should be independent of the configuration size. Previous estimates (Memos 147, 199, 265, 274, & 277) are well considered. Although it does impact the array observing efficiency, this recalibration overhead does not directly affect the array reconfiguration time, so it is not included it the totals below.

In estimating overall reconfiguration times (Figure 2), I used a short work day of 5 h, which represents a single shift working under non-ideal conditions. Although this short day is somewhat pessimistic, it may be close to the effort sustainable over long periods, for example a couple of weeks. Reconfigurations would, of course, be faster if a longer day, say 10 h, could be realized by two shifts working under more ideal conditions. This might be achieved for short periods, say for a few days when moving between the small configurations.

Moving between the smaller configurations is relatively quick. Even with only one active transporter and short (5 h) days, the array could be reconfigured in less than two weeks. With three transporters working long (10 h) days, reconfiguration will only last a few days. Furthermore, on these scales the topographic constraints of the site are relatively mild (Memos 160 & ZZZ), so rescalable (zoom) configurations (Memo 260) may be practical that would keep the array productive during reconfiguration.

Reconfiguration times for the 3 km configuration are not dramatically longer than for the smaller configurations. This is no great surprise, of course, since the transporter specifications were set to allow rapid deployment into this configuration. The topographic constraints are, however, more severe than for the smaller configurations, so rescalable designs may be difficult or impractical. In this case, the reconfiguration time is less than a week only if three transporters work simultaneously.

For the 10 km configuration, on the other hand, reconfiguration times are less than two weeks only if more than three transporters are operated simultaneously. Moreover, the topographic constraints, especially Cerro Chascon, are quite severe, so rescalable configurations are not under consideration. In the case of a 20 km configuration, the situation would be proportionally worse. Since only one or two antennae could be moved per day by each transporer, a full reconfiguration with three transporters would take more than three weeks.

The topographic constraints and transport times illustrate a paradox for continuous antenna movement between rescalable configurations. In the smaller configurations (150 m–1.1 km), where rescalable designs are easiest to lay out, there will be little operational difference compared with discrete moves between fixed configurations because reconfiguration times are short anyway. For the extended configurations (3, 10, & 20? km), on the other hand, where reconfiguration times are longer and the potential loss of array productivity is greater, rescalable configurations would be difficult or impractical to implement.

Configuration Cycle

The relative cost of reconfiguration depends on the reconfiguration frequency and on the duration of observations in each configuration. In other words, two weeks of reconfiguration would be less painful if it occurred only once a year rather than monthly. Because it will take significantly longer to move antennae into the largest, 10 km configuration than into the smaller configurations, it is attractive to deploy this configuration less often. If warranted by the scientific demand, it would be more efficient to spend longer observing in the 10 km configuration for each deployment than to deploy it more often. On the other hand, expedient service for the expected diversity of scientific programs will require a timely cycle through the available configurations. For instance, synodic observations of exoplanets might place particular requirements on the reconfiguration schedule.

Although a detailed cost-benefit analysis of reconfiguration frequency and cylce period should be performed, consider, as an example, an 18 month (548 day) cycle where the array is reconfigured every other month. In this example, which includes (desirable) seasonal precession, the 10 km configuration is used once each cycle and the smaller ones twice (Table 3). During the cycle, there are four small moves, three intermediate moves, and two long moves. With three simultaneous transporters working 5 h per day, 10% of the cycle (56.5 days) will be spend reconfiguring the array. The exact configuration sequence would have a minor effect on the overall reconfiguration time. Sustaining longer work days or operating more transporters simultaneously would proportionaltely reduce the reconfiguration overhead.

The necessary antenna transport capacity is determined by the largest configurations. With a 10 km configuration, the ALMA should have no less than three active antenna transporters during reconfiguration. Moreover, during construction, new antennas must be transported from San Pedro to Chajnantor, perhaps monthly. In between antenna deliveries, a transporter may be needed in San Pedro to manipulate partially assembled antennas. This pattern will likely continue during operations because of antenna overhauls or revisons. In any event, a spare transporter is desirable in case of breakdowns, etc. Hence the ALMA should have at least four transporters, so no less than three are active during reconfiguration.

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References

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Guilloteau, S., 1999, ALMA Memo 274

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Holdaway, M. A., & Owen, F. N., 1995, ALMA Memo 147

Table 1: Transport Specifications

antenna pickup or dropoff	15 min	Antenna RFP
transporter speed		
flat terrain	$10\,\mathrm{km\,hr^{-1}}$	Project Book, chap. 4
10% uphill	$5\,\mathrm{km\,hr^{-1}}$	Project Book, chap. 4
unloaded	$20\,\mathrm{km\,hr^{-1}}$	Project Book, chap. 4
maximum wind speed	$16\,\mathrm{m\,s^{-1}}$	Project Book, chap. 4

Table 2: Transport Times

Configuration	*Average*	*Maximum*	*Rate*[a]
150 m–1.1 km	60 min		5
3 km	75 min	1.75 h	4
10 km	2.5 h	3.75 h	2
20 km	4 h	7 h	1

[a]Average Antennae transporter^{-1} day^{-1} for 5 h work day.

Holdaway, M. A., Gordon, M. A., Foster, S. M., Schwab, F. R., & Bustos, H., 1996, ALMA Memo 160

MMA Project Book, Version 2.52, 1999 August 26

Yun, M. S., 1999, ALMA Memo 277

Yun, M. S., & Kogan, L., 1999, ALMA Memo 265

Table 3: Configuration Cycle

Reconfiguration			*Month*	*5 h days*[a]	*10 h days*[a]
	...				
150 m	→	450 m	Jan	4.5	2.2
450 m	→	1.1 km	Mar	4.5	2.2
1.1 km	→	3 km	May	5.5	2.7
3 km	→	10 km	Jul	11	5.5
10 km	→	150 m	Sep	11	5.5
150 m	→	450 m	Nov	4.5	2.2
450 m	→	1.1 km	Jan	4.5	2.2
1.1 km	→	3 km	Mar	5.5	2.7
3 km	→	150 m	May	5.5	2.7
150 m	→	450 m	Jul	4.5	2.2
450 m	→	1.1 km	Sep	4.5	2.2
1.1 km	→	3 km	Nov	5.5	2.7
3 km	→	10 km	Jan	11	5.5
10 km	→	150 m	Mar	11	5.5
150 m	→	450 m	May	4.5	2.2
450 m	→	1.1 km	Jul	4.5	2.2
1.1 km	→	3 km	Sep	5.5	2.7
3 km	→	150 m	Nov	5.5	2.7
150 m	→	450 m	Jan	4.5	2.2
	...				

[a]Three simultaneous transporters.

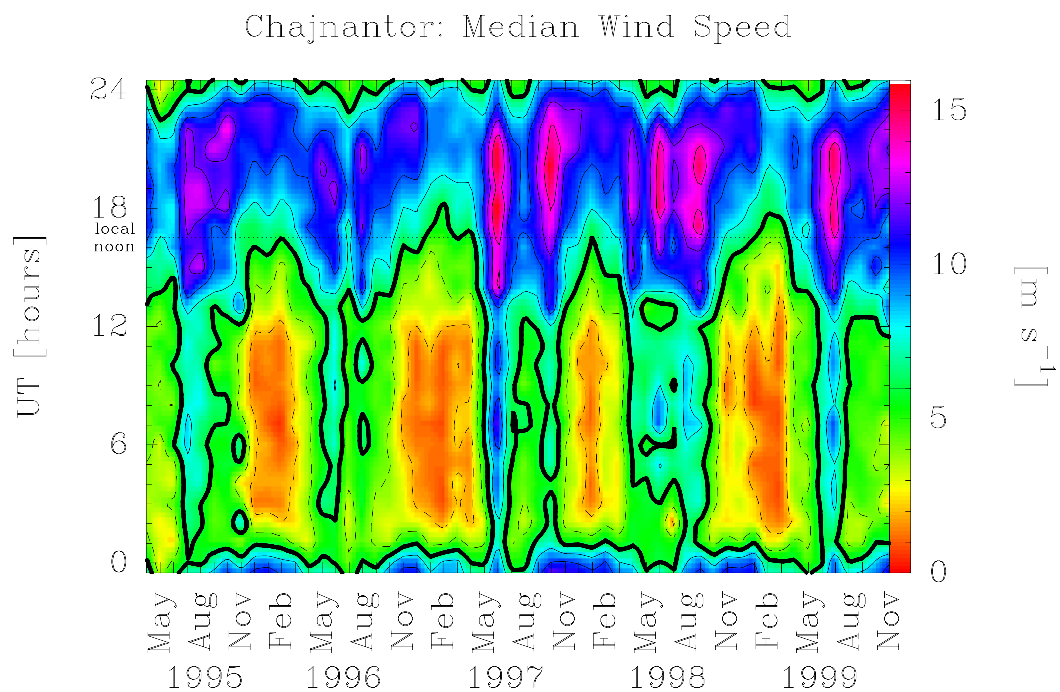

Figure 1: Hourly-monthly median wind speed at Chajnantor. Heavy contour is overall median, $6\,\mathrm{m\,s^{-1}}$, and contour interval is $2\,\mathrm{m\,s^{-1}}$. Local Solar time is UT $-$ 4.5 h.

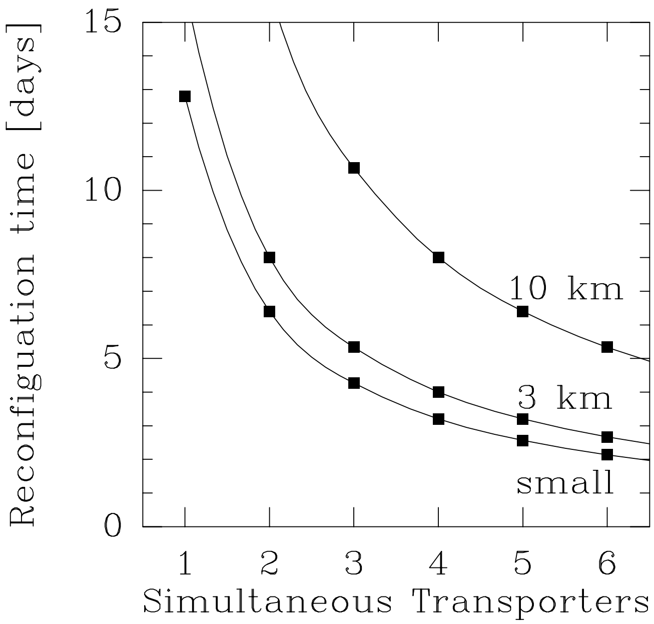

Figure 2: Reconfiguration times for 5 h work days.