CCSDS Tracking Data Message
Early Implementation Experiences

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Background

- The Consultative Committee for Space Data Systems (CCSDS) represents ISO Technical Committee 20 (Aircraft and Space Vehicles) Subcommittee 13 (Space Data & Info Transfer Systems), and has the objective of increasing space agency/operator interoperability.
  - As of 01/2009, 416 missions use CCSDS standards in some way
- CCSDS has 6 technical Areas; sub-divided into ~30 Working Groups that develop recommendations within specific technical domains
- 4 recommendations are part of the Navigation WG Technical Program:
  - Orbit Data Messages, CCSDS 502.0-B-1 (aka "ODM")
  - Tracking Data Message, CCSDS 503.0-B-1 (aka "TDM")
  - Attitude Data Messages, CCSDS 504.0-B-1 (aka "ADM")
  - Navigation Data Messages/XML Specification, CCSDS 505.0-R-2
- The TDM was the 2nd standard developed by the Nav WG
  - Began late in 2003, and was completed in November 2007
- This presentation concentrates on the infusion of the TDM standard into mission operations

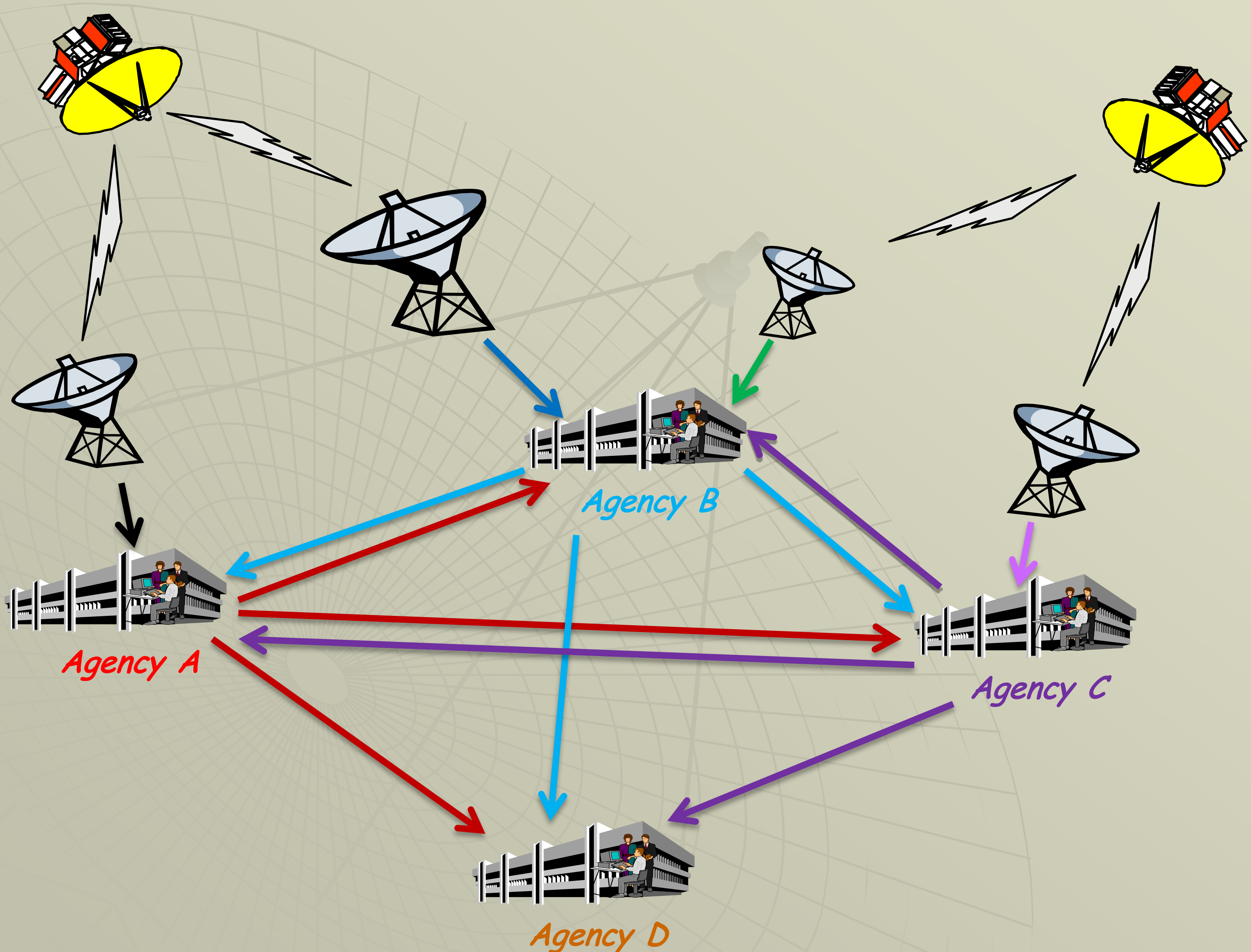
Tracking Data Message (TDM) Overview

- The TDM specifies a standard ASCII-based message format for exchanging spacecraft tracking data, in order to facilitate interagency cross-support
  - Standardization of tracking data formats facilitates allocation of tracking sessions to a more diverse set of tracking resources

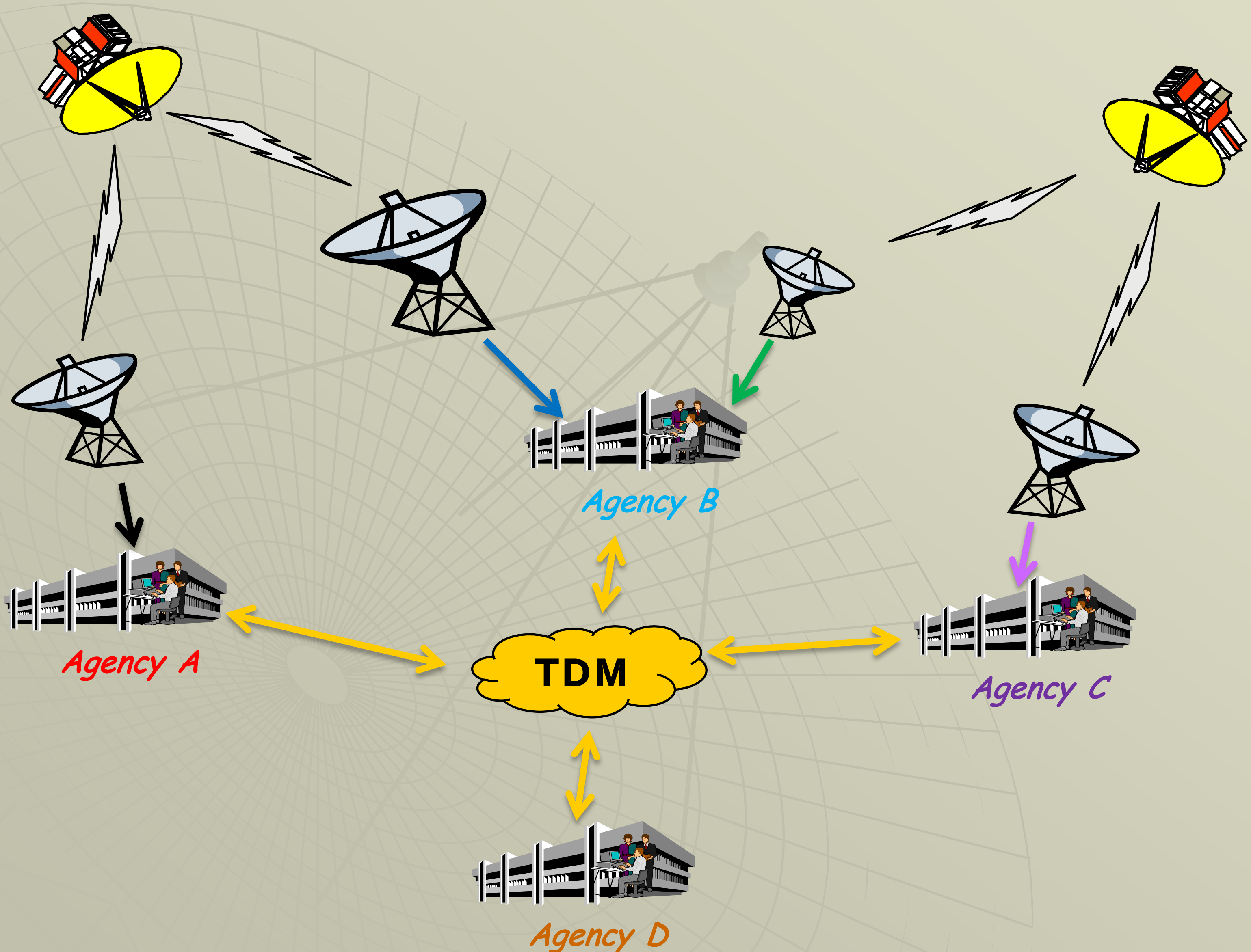
- Data Types: Doppler, transmit/received frequencies, range, angles, Delta-DOR, clock offsets, media corrections, weather
  - One primary goal for TDM was to make format and definition of data as independent as possible from tracking equipment
  - Generator of the message converts raw measurements into navigation observables in metric units, so user does not need to know how equipment operates in order to use the data

- TDM has three basic structural elements:
  - Header (identifying information)
  - Metadata section (description of the data)
  - Data section (contains the data)
- Two formats: a “keyword = value notation” (KVN) or XML

Old Model



New Model



Prototyping of the TDM

- CCSDS Standards Development Process calls for draft standards to be tested using 2 or more operational prototypes
  - Operations environment may be real or simulated
- 3 space agencies (ESA/ESOC, NASA/JPL, DLR) participated in the TDM prototyping
- Prototypes were completely independent, based on the software conventions of the 3 agencies
  - Prototype software was not exchanged, only output of prototypes was exchanged
- Prototypes were not required to be operationally robust, however they demonstrated:
  - feasibility of TDM
  - relative ease with which it could be implemented

Implementation#1: Use of TDM for Phoenix

- ESA agreed to supplement DSN Delta-DOR tracking of Phoenix S/C
  - April 2007: Decision to provide ESA's ΔDOR data in TDM format
  - Standard not yet complete, so considerable motivation to finalize
  - Significant vote of confidence in TDM feasibility; great opportunity
- Due to short time between TDM confirmation 11/2007 and Phoenix Delta-DOR campaign 1Q/2008, first TDM implementation was necessarily of reduced scope
  - Mission-specific (Phoenix) and data-type specific (Delta-DOR)
- Strategy: ESA converts data from its agency format IFMS into TDM, transfer via SFTP, JPL converts TDM to TRK-2-18 agency format
  - Cost-effective: protects agency investments in existing processing
  - Desire: "as generic as possible" implementation to allow later use
- Issues: During checkout, analysis of test data showed need for minor re-wording in TDM conventions for synchronization of station clocks
  1. When clock offset and observable timetags were "equal", clock offset was not processed in JPL S/W, causing large errors
  2. Reverse in order of stations in calculating clock offsets from UTC caused sign difference between ESA writer & JPL reader
- Once fixed in writer/reader converters, errors did not occur in ops
- Future Action: Clarifying modifications in relevant document sections

TDM Example Delta-DOR Observable

```
CCSDS_TDM_VERS = 1.0
COMMENT Quasar CTD 20 also known as
J023752.4+284808 COMMENT (ICRF), 0234+285 (IERS)
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

META_START
TIME_SYSTEM = UTC
START_TIME = 2004-136T15:42:00.0000
STOP_TIME = 2004-136T16:02:00.0000
PARTICIPANT_1 = VOYAGER1
PARTICIPANT_2 = DSS-55
PARTICIPANT_3 = DSS-25
MODE = SINGLE_DIFF
PATH_1 = 1,2
PATH_2 = 1,3
TRANSMIT_BAND = X
RECEIVE_BAND = X
TIMETAG_REF = RECEIVE
RANGE_MODE = ONE_WAY
RANGE_MODULUS = 1.674852710000000E+02
RECEIVE_DELAY_3 = 0.000077
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
COMMENT Timetag is time of signal arrival at
PARTICIPANT_2.
COMMENT Tx freq is spacecraft beacon OWLT before rcv
time
DOR = 2004-136T15:42:00.0000 -4.911896106591159E-03
DOR = 2004-136T16:02:00.0000 1.467382930436399E-02
TRANSMIT_FREQ_1 = 2004-136T14:42:00.0000
8.415123456E+09
DATA_STOP

META_START
TIME_SYSTEM = UTC
START_TIME = 2004-136T15:52:00.0000
STOP_TIME = 2004-136T15:52:00.0000
PARTICIPANT_1 = CTD 20
PARTICIPANT_2 = DSS-55
PARTICIPANT_3 = DSS-25
MODE = SINGLE_DIFF
PATH_1 = 1,2
PATH_2 = 1,3
TRANSMIT_BAND = X
RECEIVE_BAND = X
TIMETAG_REF = RECEIVE
RANGE_MODE = ONE_WAY
RANGE_MODULUS = 1.674852710000000E+02
RECEIVE_DELAY_3 = 0.000077
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
COMMENT Timetag is signal arrival @PARTICIPANT_2.
COMMENT Tx freq is ref for 2-stn interferometer.
VLBI_DELAY = 2004-136T15:52:00.0000 -1.911896106591159E-
03
TRANSMIT_FREQ_1 = 2004-136T15:42:00.0000
8.415123000E+09
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = DSS-25
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:41:00.0000 -4.59e-7
DATA_STOP
```

Implementation#2: Use of TDM for Chandrayaan-1

- JPL Navigation support contracted by ISRO for Chandrayaan-1
- Required exchange of radio metric tracking data from many tracking assets for parallel orbit determination
  - ISRO, NASA/DSN, APL, United Space Network & others
- JPL & ISRO agreed to use CCSDS TDM for data exchange
- Short time frame (~3 months) to develop/test TDM conversion S/W
- Existing JPL TDM reader source code used as baseline; already contained fundamental code to parse the message
- At a Technical Interchange Meeting, JPL presented TDM description and DSN data in TDM format to ISRO; within a day ISRO processed the DSN data and provided ISRO tracking data in TDM format

- Using the TDM:
  - Avoided complex, agency-specific data formats that would be time consuming to develop/test, and may not be re-useable
    - TDM processors form a foundation for future use with other agencies (extensions/modifications may be necessary)
  - Allowed each agency to focus immediately on potential issues with fundamental Doppler & range measurement conventions

TDM Example: Two-Way Frequency Data for Doppler Observable Calculation

```
CCSDS_TDM_VERS=1.0
COMMENT TDM example created by yyyyy-nnnA Nav Team
CREATION_DATE=2005-184T20:15:00
ORIGINATOR=NASA/JPL
META_START
TIME_SYSTEM=UTC
START_TIME=2005-184T11:12:23
STOP_TIME=2005-184T13:59:43.27
PARTICIPANT_1=DSS-55
PARTICIPANT_2=yyyy-nnnA
MODE=SEQUENTIAL
PATH=1,2,1
INTEGRATION_INTERVAL=1.0
INTEGRATION_REF=MIDDLE
FREQ_OFFSET=0.0
META_STOP
DATA_START
TRANSMIT_FREQ_1=2005-184T11:12:23     7175173383.615373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:23  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:24     7175173384.017573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:24  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:25     7175173384.419773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:25  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:26     7175173384.821973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:26  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:27     7175173385.224173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:27  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:28     7175173385.626373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:28  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:29     7175173386.028573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:29  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:30     7175173386.430773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:30  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:31     7175173386.832973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:31  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:32     7175173387.235173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:32  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:33     7175173387.637373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:33  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:34     7175173388.039573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:34  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:35     7175173388.441773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:35  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:36     7175173388.843973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:36  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:37     7175173389.246173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:37  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:38     7175173389.648373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:38  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:39     7175173390.050573
RECEIVE_FREQ_1=2005-184T13:59:27.27  8429753135.986102
RECEIVE_FREQ_1=2005-184T13:59:28.27  8429749428.196568
RECEIVE_FREQ_1=2005-184T13:59:29.27  8429749427.584727
RECEIVE_FREQ_1=2005-184T13:59:30.27  8429749427.023103
RECEIVE_FREQ_1=2005-184T13:59:31.27  8429749426.346252
RECEIVE_FREQ_1=2005-184T13:59:32.27  8429749425.738658
RECEIVE_FREQ_1=2005-184T13:59:33.27  8429749425.113143
RECEIVE_FREQ_1=2005-184T13:59:34.27  8429749424.489933
RECEIVE_FREQ_1=2005-184T13:59:35.27  8429749423.876996
RECEIVE_FREQ_1=2005-184T13:59:36.27  8429749423.325228
RECEIVE_FREQ_1=2005-184T13:59:37.27  8429749422.664049
RECEIVE_FREQ_1=2005-184T13:59:38.27  8429749422.054996
RECEIVE_FREQ_1=2005-184T13:59:39.27  8429749421.425801
RECEIVE_FREQ_1=2005-184T13:59:40.27  8429749420.824186
RECEIVE_FREQ_1=2005-184T13:59:41.27  8429749420.204178
RECEIVE_FREQ_1=2005-184T13:59:42.27  8429749419.596043
RECEIVE_FREQ_1=2005-184T13:59:43.27  8429749418.986191
DATA_STOP
```

TDM Example: Two-Way Ranging Data

```
CCSDS_TDM_VERS = 1.0
  COMMENT TDM example created by yyyyy-nnnA Nav Team
  CREATION_DATE = 2005-191T23:00:00
  ORIGINATOR = NASA/JPL
META_START
  COMMENT Range correction applied is range calibration to DSS-24.
  COMMENT Estimated RTLT at begin of pass = 950 seconds
  COMMENT Z-height correction 0.0545 km applied to uplink
  COMMENT Z-height correction 0.0189 km applied to downlink
  TIME_SYSTEM = UTC
  PARTICIPANT_1 = DSS-24
  PARTICIPANT_2 = yyyy-nnnA
  MODE = SEQUENTIAL
  PATH = 1,2,1
  INTEGRATION_REF = START
  RANGE_MODE = COHERENT
  RANGE_MODULUS = 2.0e+26
  RANGE_UNITS = RU
  TRANSMIT_DELAY_1 = 7.7e-5
  TRANSMIT_DELAY_2 = 0.0
  RECEIVE_DELAY_1  = 7.7e-5
  RECEIVE_DELAY_2  = 0.0
  CORRECTION_RANGE = 46.7741
  CORRECTIONS_APPLIED = YES
META_STOP
DATA_START
  TRANSMIT_FREQ_1      =  2005-191T00:31:51    7180064367.3536
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:31:51    0.59299
  RANGE                =  2005-191T00:31:51    39242998.5151986
  PR_N0                =  2005-191T00:31:51    28.52538
  TRANSMIT_FREQ_1      =  2005-191T00:34:48    7180064472.3146
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:34:48    0.59305
  RANGE                =  2005-191T00:34:48    61172265.3115234
  PR_N0                =  2005-191T00:34:48    28.39347
  TRANSMIT_FREQ_1      =  2005-191T00:37:45    7180064577.2756
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:37:45    0.59299
  RANGE                =  2005-191T00:37:45    15998108.8168328
  PR_N0                =  2005-191T00:37:45    28.16193
  TRANSMIT_FREQ_1      =  2005-191T00:40:42    7180064682.2366
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:40:42    0.59299
  RANGE                =  2005-191T00:40:42    37938284.4138008
  PR_N0                =  2005-191T00:40:42    29.44597
  TRANSMIT_FREQ_1      =  2005-191T00:43:39    7180064787.1976
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:43:39    0.60774
  RANGE                =  2005-191T00:43:39    59883968.0697146
  PR_N0                =  2005-191T00:43:39    27.44037
  TRANSMIT_FREQ_1      =  2005-191T00:46:36    7180064894.77345
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:46:36    0.60989
  RANGE                =  2005-191T00:46:36    14726355.3958799
  PR_N0                =  2005-191T00:46:36    27.30462
  TRANSMIT_FREQ_1      =  2005-191T00:49:33    7180065002.72044
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:49:33    0.60989
  RANGE                =  2005-191T00:49:33    36683224.3750253
  PR_N0                =  2005-191T00:49:33    28.32537
  TRANSMIT_FREQ_1      =  2005-191T00:52:30    7180065110.66743
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:52:30    0.60983
  RANGE                =  2005-191T00:52:30    58645699.4734682
  PR_N0                =  2005-191T00:52:30    29.06158
  TRANSMIT_FREQ_1      =  2005-191T00:55:27    7180065218.61442
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:49:33    0.60989
  RANGE                =  2005-191T00:55:27    13504948.3585422
  PR_N0                =  2005-191T00:55:27    27.29589
  TRANSMIT_FREQ_1      =  2005-191T00:58:24    7180065326.56141
  TRANSMIT_FREQ_RATE_1 =  2005-191T00:49:33    0.62085
  RANGE                =  2005-191T00:58:24    35478729.4012973
  PR_N0                =  2005-191T00:58:24    30.48199
  TRANSMIT_FREQ_1      =  2005-191T01:01:21    7180065436.45167
  RANGE                =  2005-191T01:01:21    57458219.0681689
  PR_N0                =  2005-191T01:01:21    27.15509
DATA_STOP
```

Future Uses of the TDM

- DSN has plans to offer the TDM format
  - Interface document describing DSN local conventions for TDM recently released
  - Mapping between DSN's TRK-2-34 format and TDM is very straightforward
  - TRK-2-34 format contains information useful to DSN engineers in troubleshooting problems, but much of it is not very useful for navigation teams
  - TRK-2-34 format is network specific; TDM is better option for interagency tracking data exchanges.

- Providing data for Venus ephemeris improvement
  - ESA makes monthly Delta-DOR measurements of Venus Express orbiter at New Norcia & Cebreros
  - Data is correlated at ESA/ESOC and provided to NASA/JPL in the TDM format
  - CCSDS Orbit Ephemeris Message (OEM) is used to convey VEX ephemeris

Focus on the User

- Transferring spacecraft tracking data in TDM format makes sense for international co-operation
- Prototyping and early implementations have shown that the TDM is relatively easy to code, validate and use
- Agencies don't need to process the TDM directly in their orbit determination S/W
- Agencies can use their existing tracking data formats internally, and develop S/W converters between TDM and internal formats
  - Effectively extends tracking networks
- Code re-use very feasible: JPL's Chandrayaan-1 TDM code was built on Phoenix ESA Delta-DOR TDM code
- Using TDM can allow agencies to support tracking data exchange at lower cost on reduced schedule
- TDM does not require use of software developed by other agencies, thus it can be implemented by any space agency in any programming language, on any operating environment, independent of other implementations

Summary / Conclusion

- <u>OBSERVATION #1</u>: Do not need to implement entire TDM functionality TDM at once if budget, mission, time, or data type constraints exist; agencies can extend TDM code base.

- <u>OBSERVATION #2</u>: Do not need to convert internal tracking data processing to use TDM, can just implement converters:

  Agency-X format ↔ TDM ↔ Agency-Y format

- If necessary, this exchange can be abbreviated even further:

  Agency-X format → TDM → Agency-Y format

- <u>OBSERVATION #3</u>: Issues can arise in TDM operations, even though prototyping was done, though specification errors are probably reduced given prototyping. (New/modified implementations should be tested before use in nav ops.)

- <u>OBSERVATION #4</u>: TDM is in principle “network generic”, but some effort maybe required to understand underlying data types in order to properly convert to internal formats. Details should be described in Interface Control Documents.

- <u>OBSERVATION #5</u>: Early uses showed positive results in general

Backup Material

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NOTE: web site references were valid as of publication date. There is no guarantee that these references will persist.