Integrated Quality Indicators and Stochastic Modelling for Real-Time Positioning: Overview and Implementation

&

Implementation of Real-Time Quality Control Procedures for Network RTK GNSS Positioning

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Outline

- **Part I**
  - **Background and Introduction to RTQC**
- **Part II**
  - **Testing (RTQC Mobile & Quality Indicators)**
- **Part III**
  - **Quality Indicators and Stochastic Modelling**
- **Conclusions and Future Work**

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Part I

Background and Introduction to RTQC

Project Background

- Use of high accuracy GNSS has increased markedly in the last decade
- Range of applications has grown beyond surveying & engineering
- Facilitated by CORS Networks and Network RTK
- Critical decisions based on GNSS have increased as a result
- Challenges for CORS provider, manufacturers, researchers

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Project Background

- **Ensuring GNSS derived positions are**
  - **High quality**
  - **Dependable**
  - **Fit-for-purpose**
- **Current Quality indicators are not always reliable**
- **Generally a measure of precision is conveyed**
  - **Often overestimated**
  - **Precision is not accuracy**

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Examples

GPS POS	PM382_VR_GNSS	WGS-84 lat	37°41'36.92643"S	WGS-84 long	144°55'58.51321"E
	120.488	Code	00400	Observation class	Wide Area Fixed
	Normal	Horz accuracy	0.016	Vert accuracy	0.018
GPS QC1	11	Relative DOPs	Yes	PDOP (max)	5.6
	3.7	VDOP (max)	4.5	RMS	19.5
	194	Horz std deviatio		Vert std deviation	
	1506	Start second	108848.0	End week	1506
	109075.0	Monitor status	Not monitored		
GPS QC2	11	Error scale	0.0077612293	VCV xx	0.0000386318
INITIALIZATION	Lost	GPS week	1506	GPS seconds	107131.0
	On the fly	Survey type	Real Time	Init counter	6
	<no text>	Plate azimuth	<null>	Plate H.Dist	<null>
	<null>				
INITIALIZATION	Gained	GPS week	1506	GPS seconds	107414.0
	On the fly	Survey type	Real Time	Init counter	7
	<no text>	Plate azimuth	<null>	Plate H.Dist	<null>
	<null>				
POINT DESIGN	PM382_VR	Method	To the Point		
PT GRID D	0.759	Delta Easting	-0.224	Delta Elevation	1.748
NOTE	11/17/2008 Time 17:24:53				

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Examples

Point Derivations

Observations or coordinates in red are out of tolerance. They have not been used to determine the coordinate of the point

Resultant coordinates for point : S2A03

Easting	Northing	Elevation	Height
387709.200m	5857413.466m	343.356m	351.667m

ID	Used to calc.	Status	Δ East	Δ North	Distance (Horiz)	Δ Elevation	Δ Height
B6 (Buxton-S2A03)		Check	0.239m	0.207m	0.317m	-1.402m	-1.402m
B7 (Buxton-S2A03)		Check	-0.005m	-0.019m	0.019m	0.133m	0.133m
B9 (Buxton-S2A03)	ENeh	Enabled	0.000m	0.000m	0.000m	0.000m	0.000m
T252 (S2A02-S2A01-S2A03)		Enabled	0.020m	0.004m	0.020m	-0.009m	-0.009m
T752 (S2A03-S2A04-S2A03)		Backsight	0.000m	0.000m	0.000m	-0.010m	-0.010m
T1035 (S2A03-S2A04-S2A03)		Backsight	0.006m	-0.002m	0.007m	-0.003m	-0.003m
T1276 (S2A03-S2A04-S2A03)		Backsight	0.001m	-0.002m	0.002m	-0.005m	-0.005m
T1254 (S2A03-S2A05-S2A03)		Backsight	0.001m	-0.002m	0.003m	-0.003m	-0.003m
T1275 (S2A03-S2A05-S2A03)		Backsight	0.002m	0.001m	0.002m	-0.003m	-0.003m

Property	Value
Baseline	B6
RMS	0.003m
H. Precision	0.056m
V. Precision	0.236m

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Examples

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T1275 (S2A03-S2A05-S2A03)		Backsight	0.002m	0.001m	0.002m	-0.003m	-0.003m

Property	Value
Baseline	B7
RMS	0.002m
H. Precision	0.021m
V. Precision	0.047m

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Examples

Point Derivations

Observations or coordinates in red are out of tolerance. They have not been used to determine the coordinate of the point

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T1254 (S2A03-S2A05-S2A03)		Backsight	0.001m	-0.002m	0.003m	-0.003m	-0.003m
T1275 (S2A03-S2A05-S2A03)		Backsight	0.002m	0.001m	0.002m	-0.003m	-0.003m

Property	Value
Baseline	B9
RMS	0.002m
H. Precision	0.003m
V. Precision	0.006m

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Introduction to RTQC

- CRC for Spatial Information Project 1.2, 1.12
  - Quality Control Issues for Real Time Positioning
- Provide quality indicators (in real time) that are
  - Reliable
  - Reflect that Mobile Users rely on their own and CORS data
- RTQC (Real-Time Quality Control)
  - Independently assesses quality of positioning in real-time
  - Uses raw measurement data (free from manufacturer algorithms)
  - Integrates CORS Network and Mobile User quality data

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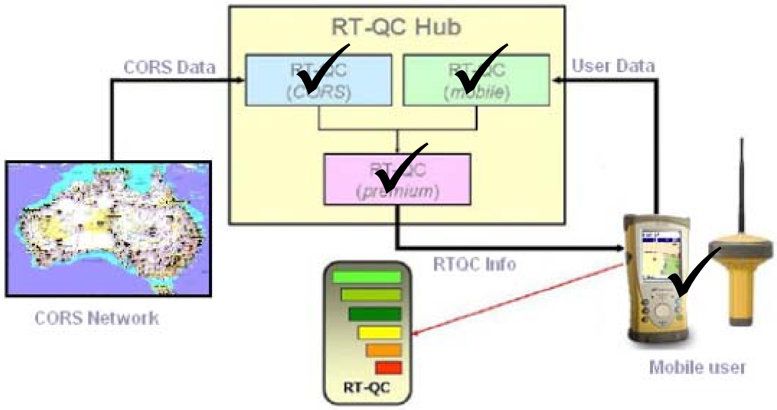
RTQC System Design



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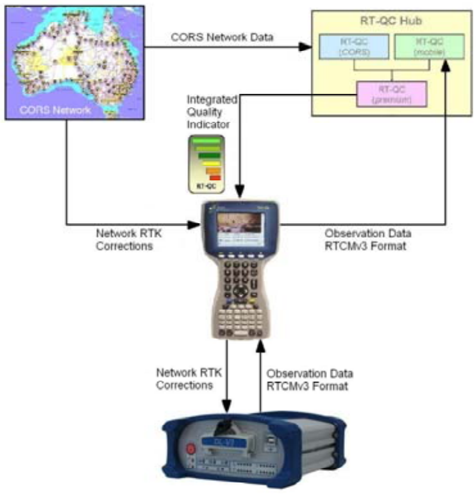
Part II

Testing (RTQC Mobile & Quality Indicators)

RTQC Mobile



RTQC Mobile (Data Formats)

- Designed to use open standards
  - RTCM 3.x via NTRIP
- Some receivers unable to transmit RTCM in "rover" mode
  - Proprietary formats to overcome this problem
- Quality Information provided to Mobile Users via RTCM
  - RTCM Message 4082
  - Licensed to CRC-SI
  - Open (ask us about it)

RTQC Mobile (Data Formats)

- Proprietary formats in red are currently supported by RTQC

Manufacturer	Format	RTCM3 from Rover
Trimble	RT17/RT27, CMR/CMR+/CMRx	×
Leica	LB2, 4G	×
Novatel	RANGE	×
Topcon	TPS	✓
Javad	JPS	✓
Ashtech	MBEN/PBEN, DBEN, ATOM	×
Sokkia	RANGE	×

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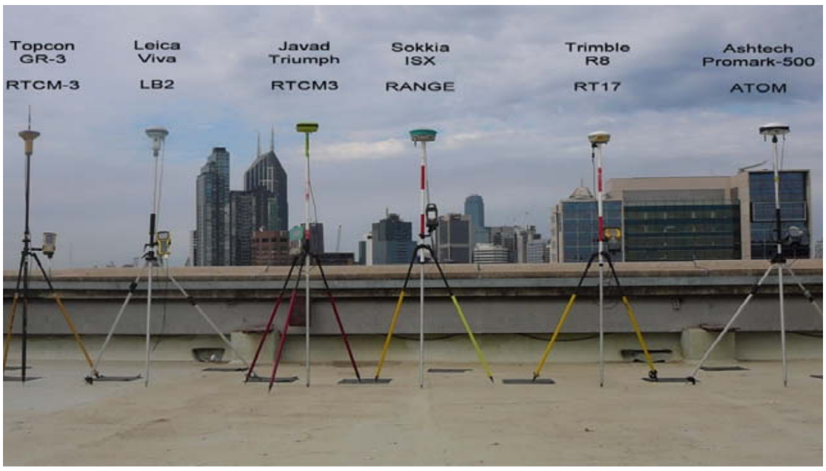
RTQC Mobile (Testing – March '10)



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RTQC Mobile (Testing – Sydney Train Survey)

- RTQC system was given its first test on a kinematic railway survey in Sydney
- 2 receivers were configured to stream data to RTQC and receive quality information during a 25km railway survey

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Sydney Train Survey Route

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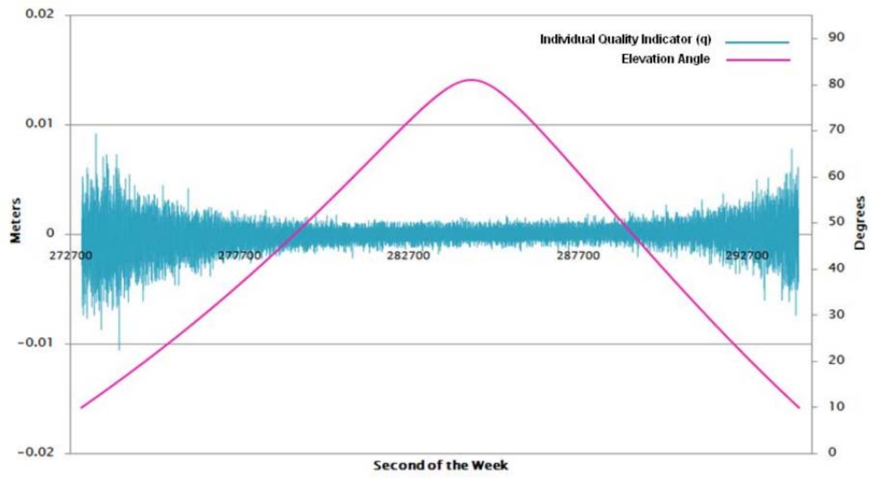
RTQC Quality Assessment

- RTQC provides several stages of quality assessment
- Sydney Train Survey examined two of these:
  1. Individual Quality Indicators
  2. Integrated Quality Indicators

RTQC Individual Quality Indicators

- Individual quality indicators (*q*) are formed for each satellite-receiver combination.
- *q* is derived from raw measurements and is indicative of the level of noise present in the observations.

Individual Quality Indicator (An Example)



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RTQC Testing – Results (Individual Indicators)

- Confirmed basic properties of individual indicators
  - Indicative of the level of noise in the observation data

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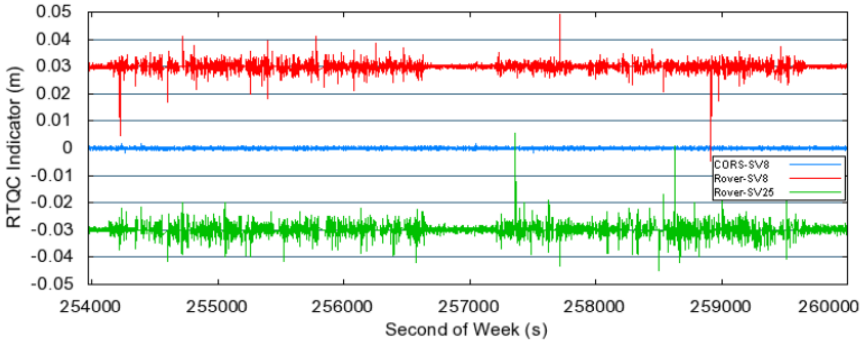
RTQC Testing – Results (Individual Indicators)



	CORS		ROVER			
			Stationary		Moving	
	Mean (mm)	*Std Dev (mm)*	*Mean (mm)*	*Std Dev (mm)*	*Mean (mm)*	*Std Dev (mm)*
SV8	0.0	0.4	0.0	0.6	-0.1	2.0
SV25	0.0	0.5	0.2	1.1	0.1	2.7

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RTQC Testing – Results (Individual Indicators)

- **Confirmed basic properties of individual indicators**
  - **Indicative of the level of noise in the observation data**
- **Analysis of outliers In individual indicators**
  - **Ground truth data (rail line) only decimeter level**
  - **Unable to compare quality indicators to coordinate deviations.**
- **Examined individual indicators prior to loss of initialisation**
  - **50% more outliers in the lead up to loss of initialisation (compared to normal epochs)**
  - **Not as discriminating as we thought it would be**
  - **Why?**

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RTQC Quality Assessment

- RTQC provides several stages of quality assessment
- Sydney Train Survey examined two of these:
  1. Individual Quality Indicators
  2. Integrated Quality Indicators

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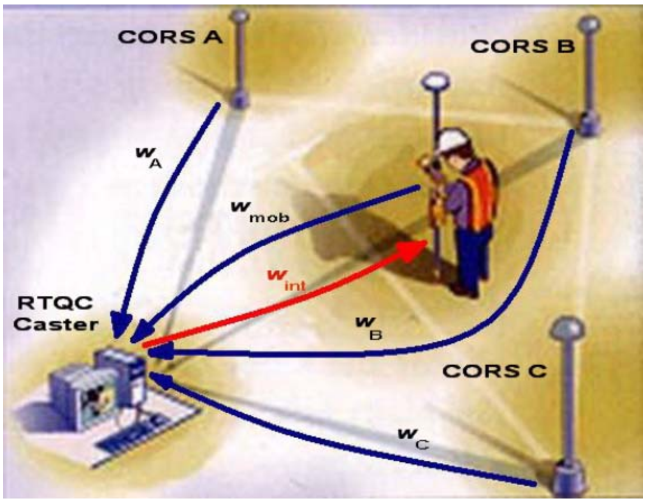
Integrated Quality Indicator



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Integrated Quality Indicator

- Individual indicators (*q*) are aggregated to form a single receiver-based indicator (*w*)
- *w* is formed using the following equation:

$$\mathrm{w} = \frac{1}{\mathrm{n}} \sum_{i=1}^{n} \frac{(q_i - \overline{q}_i)}{\sigma_{q_i}}$$

- *w* is formed for each CORS and Mobile receiver

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Integrated Quality Indicator

- CORS and Mobile Indicators are combined to form an Integrated Indicator (w_{int})

$$w_{cors} = \frac{1}{\sum \alpha_i} \sum \alpha_i w_i$$

$$w_{int} = 0.75 w_{cors} + 0.25 w_{mob}$$

$$\alpha_i = \frac{1}{d_i}$$

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RTQC Testing – Results (Integrated Indicators)

- Analysis of outliers In integrated indicators
  - Ground truth data (rail line) only decimeter level
  - Unable to compare quality indicators to coordinate deviations.
- Examined L1 residuals from LGO PPK Solution
  - Problematic, only small patches of fixed L1 solutions
  - 10 outliers detected via integrated indicator
  - 8 (80%) corresponded to significant L1 residuals
  - Promising, but inconclusive (not enough test results)

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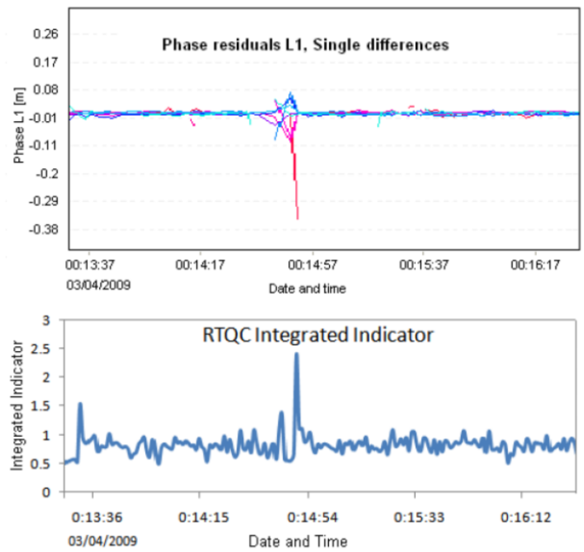
RTQC Testing – Results (Integrated Indicator)



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RTQC Testing Results – Summary

- RTQC Quality Indicators – Successful
  - Hampered by lack of accurate ground truth data
  - Confirmed basic properties of RTQC Quality Indicators
  - Encouraging results for both individual and integrated indicators
  - Improved testing and additional analysis required
- RTQC Mobile – Very Successful
  - No major communications issues or other problems
    - Network RTK (UNSW)
    - RTQC (Melb Uni)
    - 2-Way Mobile Internet (Telstra NextG)

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Part III

Quality Indicators and Stochastic Modelling

The Stochastic Model

- GNSS processing is based around least squares (LSQ)
  - $(A^T V_m^{-1} A)^{-1} A^T V_m^{-1} m_r$
- LSQ requires (as a minimum)
  - Observations
  - Stochastic Model
  - Functional model
  - Unknown Parameters
- Stochastic Model
  - describes the noise present in the observations
  - represented by a Variance Covariance (VCV) Matrix

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Why is the Stochastic Model important?

- A correctly defined stochastic model
  - correctly “weights” the GNSS observations in the LSQ algorithm
  - aids the ambiguity resolution process
  - can Improve coordinate estimates
  - can improves the reliability of coordinate precision estimates

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Stochastic Modelling

- Stochastic Models used in practice include:
  - Elevation Dependent Model
  - SNR (or C/N0) Models (various)
- Only provide variance terms in the VCV Matrix
- Ignore covariances (correlations) between observations
- Three types of physical correlations exist
  - spatial correlations (between satellites)
  - temporal correlations (between epochs)
  - inter-frequency correlations (between frequencies)

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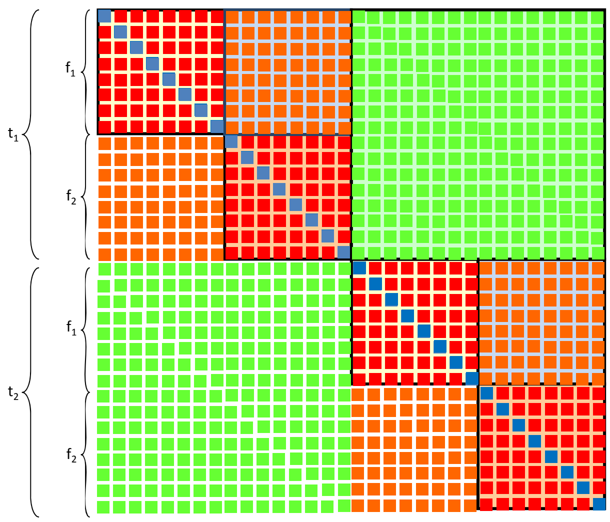
Variance-Covariance Matrix



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Quality Indicators & Stochastic Modelling

- RTQC Individual Quality Indicators
  - Calculated directly from observation data (simple process)
  - Indicative of noise in the observations
- Compute variances directly from quality indicators
- Compute covariances directly from quality indicators
- Examine covariances for evidence of correlation

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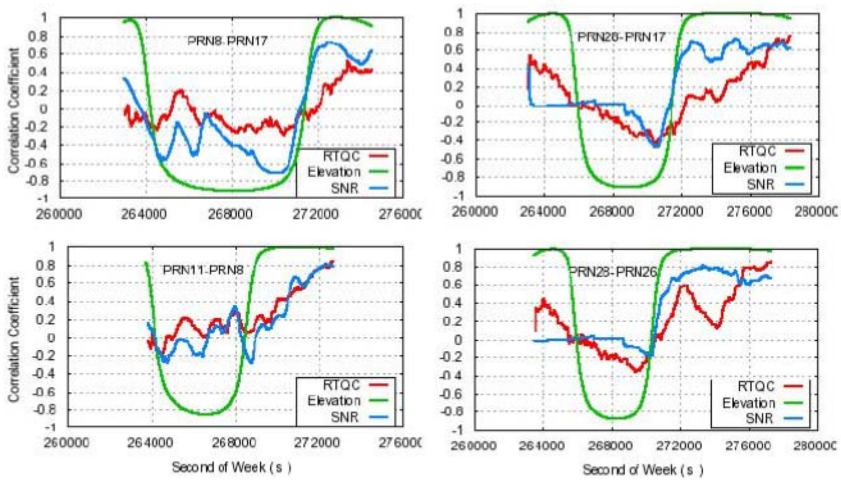
Stochastic Modelling – Spatial Correlations



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Future Work

- Quality Indicators
  - Improve testing and analysis
- Stochastic Modeling
  - Investigation of temporal and inter-frequency correlations
  - Rigorous testing of the model
- Recent advance (last week)
  - Incorporation of Reverse RTK into RTQC to facilitate the rigorous testing of the stochastic model
  - Yong Heo (UNSW)

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Cody Corporation – Luke Fulton, Bryan Robinson

GlobalPos – Brad Stephenson

Lightwave Technology – Justin Davies

Ultimate Positioning – Paul Standen, Paul Andrews


LASER HAZARD
LIVE BOMBS
NO TRESPASS
DANGER
MILITARY RANGE BOUNDARY
LIVE FIRING
DO NOT ENTER
RTQC – It will keep you out of trouble!