

Computational Modeling using Multiple Resource Theory (cMRT)

Wickens (2002) presents an update to his widely applied Multiple Resource Theory (MRT) of dual-task interference. Here he discusses the extension of the model via the addition of a fourth (but nested) dimension within the visual perceptual modality; namely, the Visual Channel dichotomy (focal vs. ambient streams). The four dimensions of the MRT now include:

- I(a). Perceptual Modality (Visual / Auditory)
- I(b). Visual Channel (Focal / Ambient)
- II. Processing Code Format (Spatial / Verbal)
- III. Information Processing Stage ([Perception / Cognition] / Responding)

More importantly perhaps, Wickens (2002) also outlines an approach for constructing an instance of a computational model based upon MRT. Horrey and Wickens (2003) describe such an instance of computational MRT (cMRT) modeling in the dual-task domain of automobile driving vs. in-vehicle technology usage. A graphical representation of their situation-specific cMRT model is depicted in Figure 1. A summary of their cMRT computations follows thereafter.

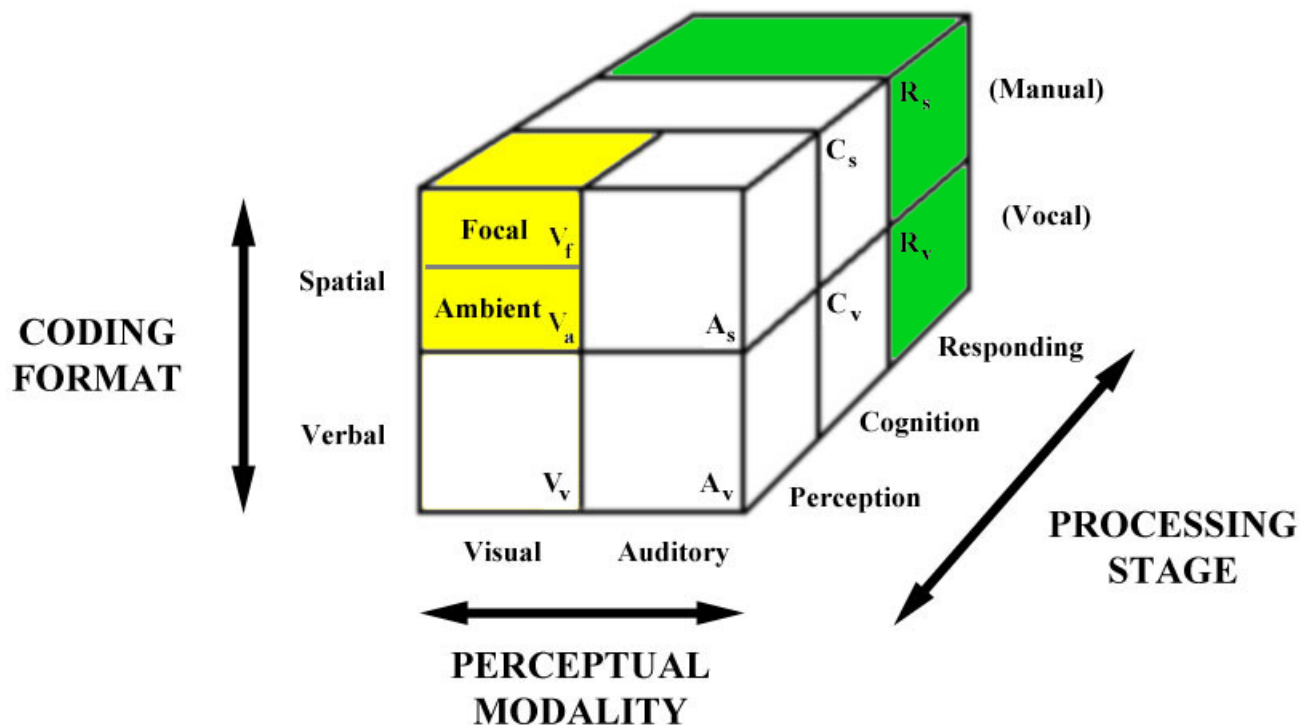


Figure 1. Automobile driving instance of the Multiple Resource Theory of dual-task interference

The instance of MRT depicted in Figure 1 represents 8 unique resources for which dual tasks can compete: visual-focal (V_f), visual-ambient (V_a), auditory-spatial (A_s), auditory-verbal (A_v), cognitive-spatial (C_s), cognitive-verbal (C_v), response-spatial (R_s) and response-verbal (R_v).

The first step in implementing a cMRT model is to construct a **Conflict Model** which captures the degree to which two tasks may interfere with each other for all possible resources to be represented in the domain of interest. A blank form representing an instance of the Conflict Model (i.e., the **Conflict Matrix**) is depicted in Figure 2. The “expected” level of resource-vs-resource interference (based upon the domain and the modeler’s expertise) is represented by a coefficient ranging from 0.0 (primary-secondary tasks share perfectly without interference) to 1.0 (the tasks cannot share the resource at all; e.g., you can’t give two vocal responses simultaneously). In practice, Horrey and Wickens (2003) initialized the starting value of each cell in the Conflict Matrix to 0.2 in order to capture the “cost of concurrence” (i.e., resources consumed by the central executive for task management overhead). Next, they added an increment of interference (i.e., 0.2) to each cell based upon each dimension of the MRT model shared by the two competing resources represented by the cell. Finally, additional “tweaks” to the amount of interference represented in each cell were made in order to capture unique requirements of the test domain as well as the past experience and expertise of the modeling team.

Conflict Matrix

	V_f	V_a	A_s	A_v	C_s	C_v	R_s	R_v
V_f								
V_a								
A_s								
A_v								
C_s								
C_v								
R_s								
R_v								

Figure 2. Conflict Matrix structure used to capture the structural interference between dual tasks.

The Conflict Matrix constructed by Horrey and Wickens (2003) is shown in Figure 3.

Conflict Model
(Horrey & Wickens, 2003)

	V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v
V _f	0.8	0.6	0.6	0.4	0.7	0.5	0.4	0.2
V _a		0.8	0.4	0.6	0.5	0.7	0.2	0.4
A _s			0.8	0.4	0.7	0.5	0.4	0.2
A _v				0.8	0.5	0.7	0.2	0.4
C _s					0.8	0.6	0.6	0.4
C _v						0.8	0.4	0.6
R _s							0.8	0.6
R _v								1.0

Figure 3. An instance of a cMRT Conflict Matrix (from Horrey & Wickens, 2003)

Before being able to utilize the Conflict Matrix to estimate the relative degree of structural task interference, a **Demand Vector** must be established for each of the tasks being modeled. The Demand Vector represents a cognitive task analysis that estimates how much task performance depends upon each of the resources being represented in the model. Each resource is assigned a coefficient value ranging from 0 to 3; such that: 0 = no dependence, 1 = some dependence, 2 = significant dependence, 3 = extreme dependence (The value of 3 should be used only in special circumstances). The sum of the coefficients assigned to the resources in the Demand Vector represents the overall nominal estimate of “difficulty” assigned to the task under consideration.

Horrey and Wickens (2003) considered three levels of primary task (automobile driving) difficulty as well as three levels of in-vehicle technology (secondary task). The Demand Vectors for each of these tasks is presented in Table 1.

Task	Demand Vector								Demand Scalar
	Perceptual				Cognition		Response		
	Vf	Va	As	Av	Cs	Cv	Rs	Rv	
(A) City Driving	2	1	0	0	2	0	1	0	6
(B) Rural Straight Driving	1	1	0	0	1	0	1	0	4
(C) Rural Curved Driving	1	2	0	0	1	0	2	0	6
(D) IVT HUD Adjacent	1	0	0	0	0	1	0	1	3
(E) IVT HDD Console	2	0	0	0	0	1	0	1	4
(F) IVT Auditory	0	0	0	2	0	2	0	2	6

Table 1. Demand Vectors for primary and secondary task conditions. IVT = In-Vehicle Task, HUD = IVT Head-up display, HDD = IVT with Head-down display; Auditory = IVT with sound display.

Given the construction of the Conflict Matrix for the domain of interest and the estimates of the Demand Vectors for the tasks being employed, all of the information necessary for computing the estimate of dual-task interference is complete. This prediction is based upon two computationally derived components:

$$\text{Total Interference} = \text{Total Demand} + (\text{Scaled}) \text{ Total Conflict}$$

The computation of each of these components is described next.

Total Demand is computed by: (1) Calculating the average demand for each of the Demand Vectors representing the two tasks being evaluated; then (2) Computing the sum of the two Demand Vector averages. For example, the Total Demand represented by concurrent performance of the primary task of City Driving and the secondary task of reading from a HUD IVT display (Tasks A and D, respectively, in Table 1 above) would be computed as follows:

Demand Vectors								
	V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v
Task A	2	1	0	0	2	0	1	0
Task D	1	0	0	0	0	1	0	1
(0=none; 1=easy; 2=moderate; 3=heavy)								
TOTAL DEMAND:								
0.75 Mean Task A 0.37 Mean Task D 1.12 Sum of Task Means (Range: 0.0 - 6.0)								

Figure 4. Computing the Total Demand parameter.

The algorithm for computing **Scaled Total Conflict** is a bit more complex. The first step in the computation is to identify all of the cells in the Conflict Matrix that are “shared” by the competing tasks under examination. Figure 5 graphically captures how this can be done. Any cell in the matrix that corresponds to a non-zero Demand Vector entry for BOTH tasks represents an opportunity for conflict. These are the cells circled in red (see Figure 5).

Task D Demand Vector		Conflict Model (Horrey & Wickens, 2003)								Task A Demand Vector	
		V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v		
		2	1	0	0	2	0	1	0		
V _f	1	0.8	0.6	0.6	0.4	0.7	0.5	0.4	0.2		
V _a	0		0.8	0.4	0.6	0.5	0.7	0.2	0.4		
A _s	0			0.8	0.4	0.7	0.5	0.4	0.2		
A _v	0				0.8	0.5	0.7	0.2	0.4		
C _s	0					0.8	0.6	0.6	0.4		
C _v	1						0.8	0.4	0.6		
R _s	0							0.8	0.6		
R _v	1								1.0		

Conflict Model
Range: 0-1; Sum of coefficients = 20.0 (max. conflict); Concurrency Cost = 0.2

Figure 5. Worksheet for computing Total Conflict between tasks using a Conflict Matrix.

The **Total Conflict** score is computed by summing the coefficients for all of the cells identified as sources of resource competition. Figure 5 shows all of the identified sites for structural conflict in the Horrey and Wickens instance of the cMRT model. The sum of these cells (0.8 + 0.6 + 0.7 + 0.4 + 0.4) represents a Total Conflict of 2.9 computed from the model. However, because the theoretical maximum value of this Total Conflict score using the current conflict model is equal to 20 (i.e., sum of all the cells in the Conflict Matrix) it becomes likely that the Total Conflict sum might “overwhelm” the contribution of the

Total Demand parameter (since its theoretical maximum value is only equal to 6). In order to minimize such effects, the Total Conflict score can be scaled so that its maximum attainable value is matched to the range of the Total Demand parameter (see von Engelen, 2011). For the current example, this can be accomplished by multiplying the Total Conflict score by a prescale value of 0.3 (i.e., maximum possible Total Demand divided by the maximum possible Total Conflict = $6 / 20 = 0.3$). Hence, given the Total Conflict score of 2.9 for the current example, the Scaled Total Conflict parameter can be computed as follows:

$$\text{Scaled Total Conflict} = 0.3 (\text{Total Conflict}) = (0.3)(2.9) = 0.87$$

Given the Total Demand incurred by the two tasks (see Figure 4) and their Scaled Total Conflict computed above, the Total Interference metric predicted by this instance of the computational model is calculated as:

$$\text{Total Interference} = \text{Total Demand} + \text{Scaled Total Conflict} = 1.12 + 0.87 = 1.99$$

References

[Horrey, W.J. & Wickens, C.D. \(2003\)](#). Multiple resource modeling of task interference in vehicle control, hazard awareness and in-vehicle task performance. *Proceedings of the 2nd International Symposium on Human Factors in Driving Assessment, Training and Vehicle Design*. Park City, UT.

[Wickens, C.D. \(2002\)](#). Multiple resources and performance prediction. *Theoretical Issues in Ergonomic Science*, 3(2), 159-177.

[von Engelen, D. \(2011\)](#). Attention Drivers! Analyzing Driver Distraction. Diploma Thesis, Computer Science Department, RWTH Aachen University, Germany

Appendices:

Blank worksheet for developing cMRT models

Horrey & Wickens (2003) cMRT computation worksheet

Sample computations for City Driving with HUD IVT display

Sample computations for Rural-Curve Driving with Auditory IVT display

cMRT model predictions (with goodness-of-fit)

Differential predictions from Total Demand versus Total Conflict components of cMRT model

Demand Vectors

	V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v
Task A								
Task B								

Mean Task A

Mean Task B

TOTAL DEMAND:

Sum of Task Means

Conflict Model

		V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v
V _f									
V _a									
A _s									
A _v									
C _s									
C _v									
R _s									
R _v									

Conflict Prescaler

$$= \frac{6}{(\text{max. conflict})} =$$

Maximum Conflict = Sum of all cells in Conflict Matrix = ____

Demand Vectors

	V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v	
Task A									Mean Task A
Task B									Mean Task B

(0=none; 1=easy; 2=moderate; 3=heavy)

TOTAL DEMAND: **Sum of Task Means**
(Range: 0.0 - 6.0)

Conflict Model

(Horrey & Wickens, 2003)

		V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v
V _f		0.8	0.6	0.6	0.4	0.7	0.5	0.4	0.2
V _a			0.8	0.4	0.6	0.5	0.7	0.2	0.4
A _s				0.8	0.4	0.7	0.5	0.4	0.2
A _v					0.8	0.5	0.7	0.2	0.4
C _s						0.8	0.6	0.6	0.4
C _v							0.8	0.4	0.6
R _s								0.8	0.6
R _v									1.0

Conflict Model; Sum of cells = 20.0 = Max. Conflict
Range: 0.0 - 1.0 (default = 0.2 = Cost of Concurrency)

Conflict = Sum(Active Cells)
= _____

Conflict Prescaler

$$= \frac{(\text{max. demand})}{(\text{max. conflict})} = \frac{6}{20} = 0.3$$

Scaled Conflict:
(Conflict * 0.3)

TOTAL INTERFERENCE:
(Total Demand + Scaled Conflict)

HORREY + WICKENS (2003) = MRT

CONDITION: TASK A = CITY DRIVING
TASK B = H.V.D. IVT

Demand Vectors

	V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v	
Task A	2	1	0	0	2	0	1	0	0.75
Task B	1	0	0	0	0	1	0	1	0.37

(0=none; 1=easy; 2=moderate; 3=heavy)

Mean Task A

Mean Task B

TOTAL DEMAND: 1.12 Sum of Task Means
(Range: 0.0 - 6.0)

Conflict Model (Horrey & Wickens, 2003)

	V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v
	2	1	0	0	2	0	1	0
V _f	1	0.8	0.6	0.4	0.7	0.5	0.4	0.2
V _a	0		0.8	0.4	0.5	0.7	0.2	0.4
A _s	0			0.8	0.7	0.5	0.4	0.2
A _v	0				0.5	0.7	0.2	0.4
C _s	0					0.8	0.6	0.4
C _v	1						0.8	0.6
R _s	0							0.6
R _v	1							1.0

$$0.8 + 0.6 + 0.7 + 0.4 + 0.4$$

Conflict = Sum(Active Cells)
= 2.9

Normalization Constant
= $\frac{(\text{max. demand})}{(\text{max. conflict})} = \frac{6}{20} = 0.3$

Normalized Conflict: 0.87
(Conflict * 0.3)

20 cells in Conflict Model; Sum of cells = 20.0 = Max. Conflict
Range: 0.0 - 1.0 (default = 0.2 = Cost of Concurrency)

TOTAL INTERFERENCE: 1.99
(Total Demand + Normalized Conflict)

$$1.12 + 0.87$$

HORREY + WICKENS (2003) cMRT

CONDITION: TASK A = RURAL-CURVE DRIVING
TASK B = AUDITORY IVT

Demand Vectors

	V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v	
Task A	1	2	0	0	1	0	2	0	0.75
Task B	0	0	0	2	0	2	0	2	0.75

(0=none; 1=easy; 2=moderate; 3=heavy)

TOTAL DEMAND: **1.50** Sum of Task Means
(Range: 0.0 - 6.0)

Conflict Model (Horrey & Wickens, 2003)

		V _f	V _a	A _s	A _v	C _s	C _v	R _s	R _v
		1	2	0	0	1	0	2	0
V _f	0	0.8	0.6	0.6	0.4	0.7	0.5	0.4	0.2
V _a	0		0.8	0.4	0.6	0.5	0.7	0.2	0.4
A _s	0			0.8	0.4	0.7	0.5	0.4	0.2
A _v	2				0.8	0.5	0.7	0.2	0.4
C _s	0					0.8	0.6	0.6	0.4
C _v	2						0.8	0.4	0.6
R _s	0							0.8	0.6
R _v	2								1.0

20 cells in Conflict Model; Sum of cells = 20.0 = Max. Conflict
Range: 0.0 - 1.0 (default = 0.2 = Cost of Concurrency)

TOTAL INTERFERENCE: **1.83**
(Total Demand + Normalized Conflict)

$$1.5 + 0.33$$

$$0.5 + 0.2 + 0.4$$

Conflict = Sum(Active Cells)
= **1.1**

Normalization Constant

$$= \frac{(\text{max. demand})}{(\text{max. conflict})} = \frac{6}{20} = 0.3$$

Normalized Conflict: **0.33**
(Conflict * 0.3)

$$1.1 \times 0.3$$

Predictions of Model versus Real-World Observations (Horrey & Wickens, 2003)

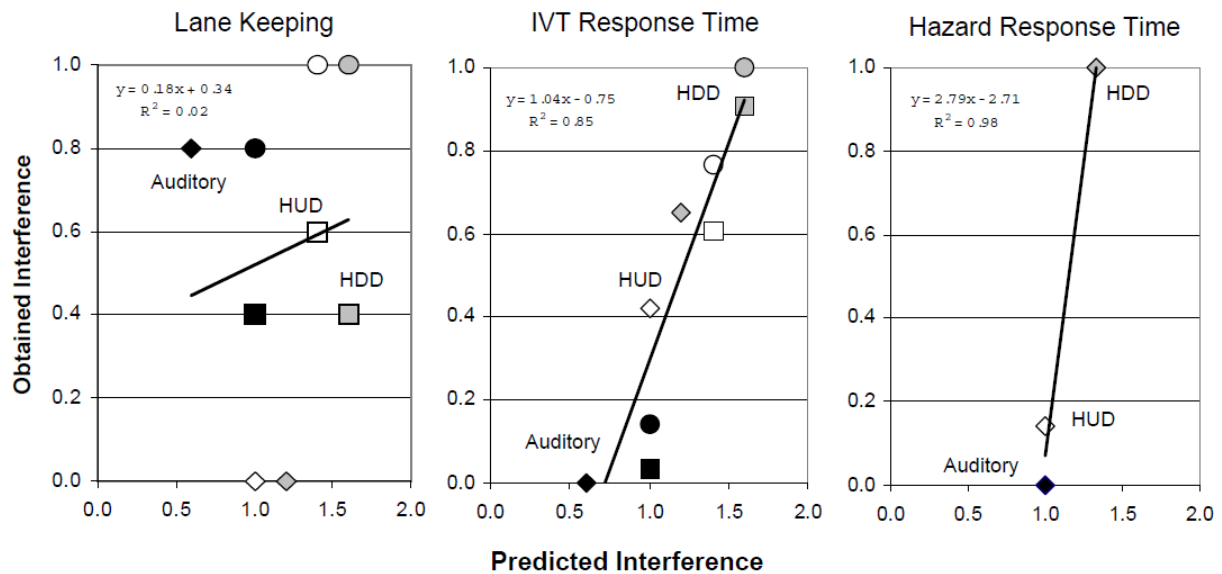
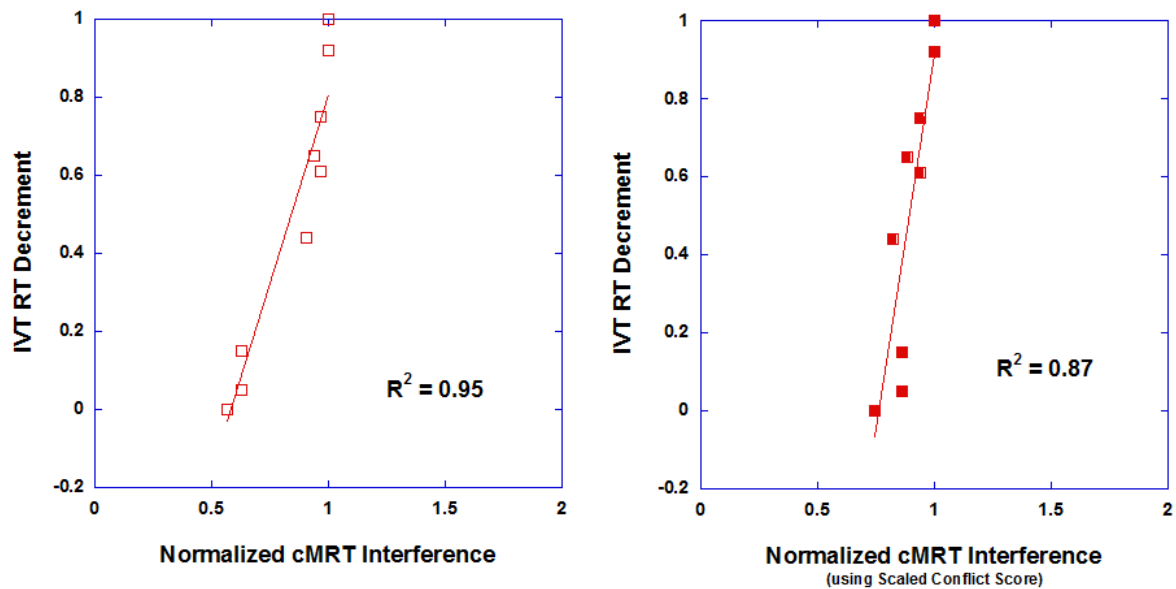
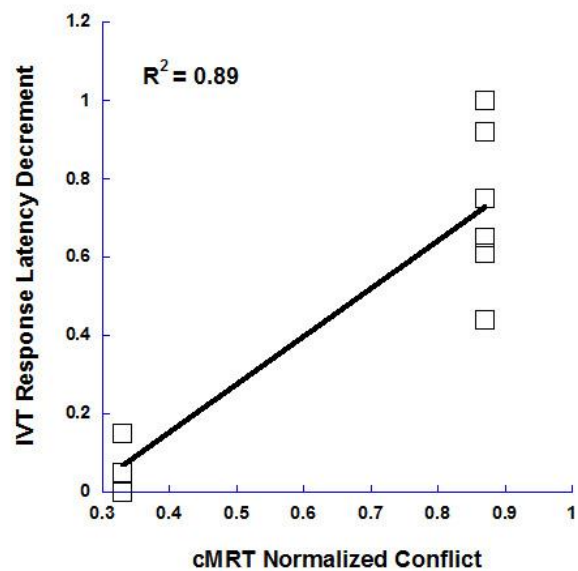
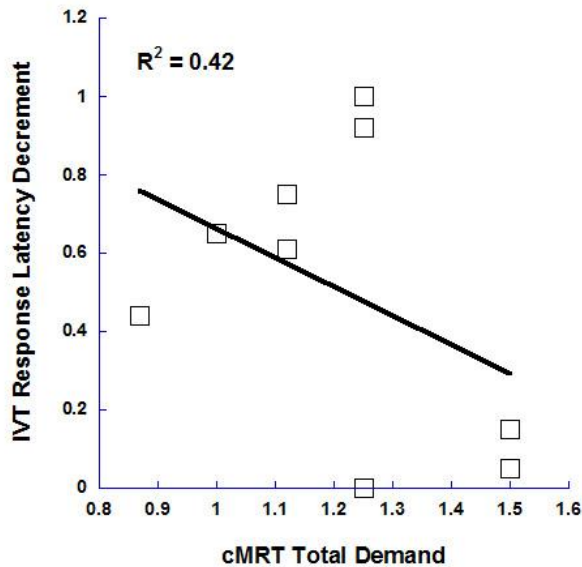


Figure 1. Obtained interference as a function of model-predicted interference for the (a) lane keeping (driving) task, (b) response times to the IVT task, and (c) hazard RTs. The HUD condition is represented by white markers, the HDD condition by light gray, and the auditory by black markers. Diamonds represent the straight rural roads, circles represent curved rural roads, and squares indicate straight urban roads.



Linear fits between predictions of cMRT model and Horrey & Wickens' (2003) observed performance data generated at USD Heimstra Lab using procedure outlined herein. IVT Response Time data interpolated from Fig. 1 (above). cMRT predictions based upon unadjusted conflict yielded an R^2 of 0.95. However, predictions using scaled Total Conflict (where max. conflict is scaled to 6) yielded an R^2 value of 0.87 (resulting from limited range in the resulting predictions). See next page for actual data points.



Performance on Horrey & Wickens (2003) IVT task as a function of either the cMRT Total Demand component or the cMRT Scaled Conflict component. Note the strange, but complementary way these components combine to constrain the overall prediction of Total Interference in the dual task paradigm.

Driving	IVT	Total				Normalized			
		Observed*	Demand	Conflict	Prediction	Prediction	Scaled Conflict	Scaled Prediction	Scaled Predict
City	HUD	0.61	1.12	2.9	4.02	0.967	0.87	1.99	0.938
City	HDD	0.92	1.25	2.9	4.15	1.000	0.87	2.12	1.000
City	Audio	0.05	1.50	1.1	2.60	0.626	0.33	1.83	0.863
Rural-Straight	HUD	0.44	0.87	2.9	3.77	0.908	0.87	1.74	0.820
Rural-Straight	HDD	0.65	1.00	2.9	3.90	0.939	0.87	1.87	0.882
Rural-Straight	Audio	0.00	1.25	1.1	2.35	0.566	0.33	1.58	0.745
Rural-Curve	HUD	0.75	1.12	2.9	4.02	0.968	0.87	1.99	0.938
Rural-Curve	HDD	1.00	1.25	2.9	4.15	1.000	0.87	2.12	1.000
Rural-Curve	Audio	0.15	1.50	1.1	2.60	0.626	0.33	1.83	0.863

*Interpolated from Horrey & Wickens (2003) Figure 1.

Frank Schieber (schieber@usd.edu)

Heimstra Human Factors Laboratories

University of South Dakota

March 1, 2012 (Revised 23 February 2016)