Example 6b: Path Analysis for Mediation Predicting Binary Outcomes
(complete syntax and output available for Mplus and STATA electronically, along with publication)

Figure 1 and Table 1 from: Hoffman, L., & McDowd, J. M. (2010). Simulator driving performance predicts accident reports five years later. *Psychology and Aging, 25*(3), 741–745.

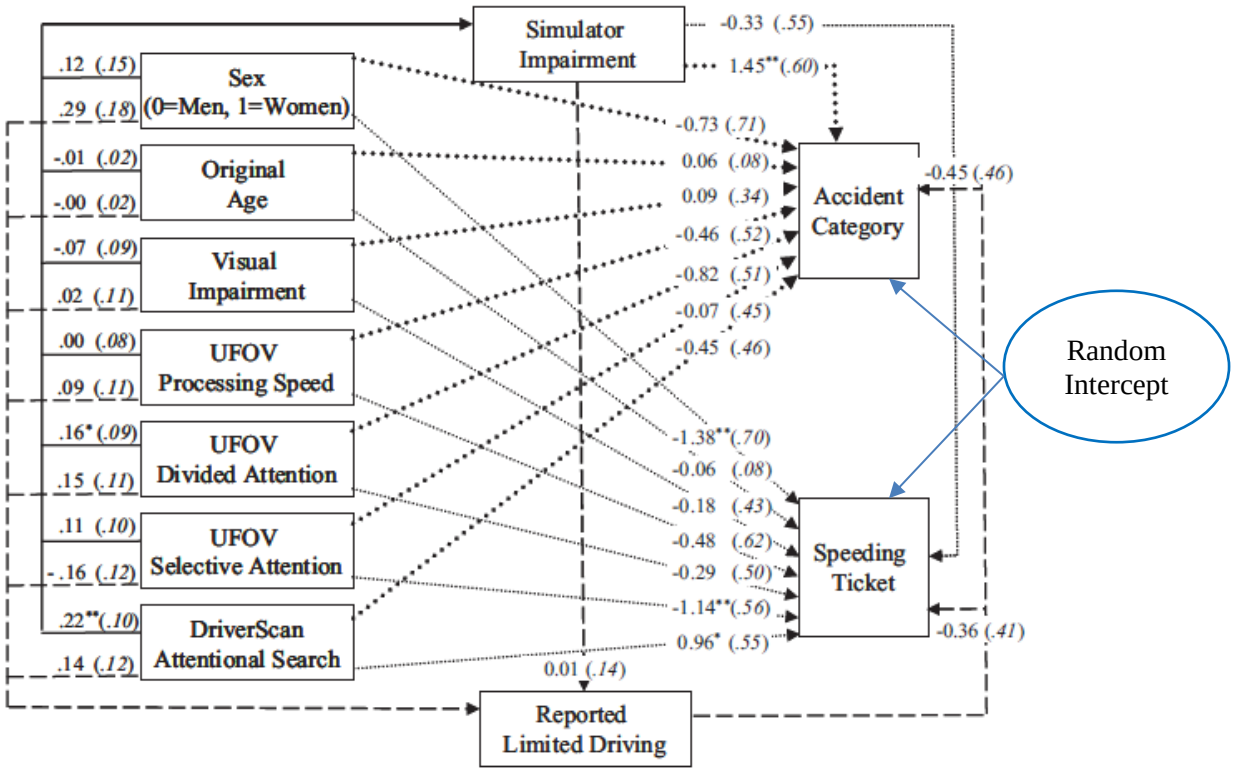
This study reports on follow-up data for 114 of 152 persons originally tested in my dissertation study conducted in 2003, which focused on the role of vision and attention in predicting simulator driving impairment. The goal was to see if any of the original study variables (left panel boxes plus simulator impairment) would predict future reports of limited driving, involvement in an at-least-partially-at-fault accident (14/114), or receipt of a speeding ticket (14/144).

For this example, the original model shown in Figure 1 was expanded to include a random intercept latent variable to create residual covariance between the two binary outcomes (which cannot be added directly when using full-information maximum likelihood estimation). I also added an indirect effect for demonstration purposes. For estimation, I switched to robust ML in Mplus, and invoked robust standard errors (to mimic robust ML) in STATA GSEM. However, because STATA GSEM did equation-wise deletion of missing cases (17 cases), the results do not match those of Mplus.

Table 1
Bivariate Correlations Between Predictor and Outcome Variables

Variable	1	2	3	4	5	6	7	8	9	10	11
Outcomes											
1. Accident report	—										
2. Speeding ticket report	−.14	—									
Predictors											
3. Reported limited driving	−.25	−.22	—								
4. Simulator impairment	.21	−.22	.14	—							
5. Sex (0 = men, 1 = women)	−.23	−.35*	.21*	.13	—						
6. Original age	.04	−.20	.05	.16	−.03	—					
7. Visual impairment	−.00	−.18	.02	.05	−.05	.22*	—				
8. UFOV processing speed	−.15	−.28	.12	.17*	−.10	.12	.13	—			
9. UFOV divided attention	−.24	−.31*	.17*	.40*	.04	.25*	.17	.30*	—		
10. UFOV selective attention	−.08	−.43*	.03	.38*	−.09	.36*	.29*	.29*	.52*	—	
11. DriverScan attentional search	−.16	−.14	.15	.43*	.06	.41*	.20*	.20*	.45*	.60*	—

Note. UFOV = Useful Field of View test.
* $p < .05$.



Mplus Syntax and Partial Output for Path Model with Random Intercept:

```
TITLE:   Example 6b: Mplus Path Analysis for Dissertation Follow-up
DATA:    FILE = driver.csv;       ! Can just list file name if in same folder;
         FORMAT = free;           ! FREE (default) or FIXED format;
         TYPE = individual;       ! Individual (default) or matrix data as input;
VARIABLE:
! List of ALL variables in original wide data file, in order;
! Mplus names must use 8 characters or fewer (so rename as needed);
  NAMES = PartID sex age75 cs_1_5 cs_3 cs_6 cs_12 cs_18 far near
          zufov1 zufov2 zufov3 Dscan lane da_task crash stop speed time
          simfac part visfac attfac limit4 ticket2 speed2 follow attr
          nacc2 jacc2 jacc20 acc2;
! List of ALL variables used in model;
  USEVARIABLE = sex age75 visfac zufov1 zufov2 zufov3 Dscan simfac
                limit4 speed2 acc2;
! Missing data identifier;
  MISSING = ALL (-999);
! Select only follow-up cases;
  USEOBS = follow EQ 1;
! Categorical outcomes;
  CATEGORICAL = acc2 speed2;

ANALYSIS: LINK = LOGIT;                    ! Link function for categorical outcomes;
          ESTIMATOR = MLR;                 ! Robust full-information maximum likelihood;
          INTEGRATION = MONTECARLO(1000);  ! Mplus required (#samples);
OUTPUT:   CINTERVAL;                       ! Print confidence intervals;
          STDYX;                           ! Print fully standardized solution, too;
          SAMPSTAT;                        ! Print descriptive statistics;

MODEL: ! * --> Estimated parameter (all listed below for clarity);

! Outcome intercepts (for continuous variables);
  [simfac* limit4*];
! Outcome thresholds (for binary variables);
  [speed2$1* acc2$1*];

! Regressions: y outcomes ON x predictors (label to do math on later, * implied);
  simfac ON sex age75 visfac zufov1 zufov2 zufov3 Dscan               (sim1-sim7);
  limit4 ON sex age75 visfac zufov1 zufov2 zufov3 Dscan simfac        (lim1-lim8);
  acc2   ON sex age75 visfac zufov1 zufov2 zufov3 Dscan simfac limit4 (acc1-acc9);
  speed2 ON sex age75 visfac zufov1 zufov2 zufov3 Dscan simfac limit4 (spd1-spd9);

! Estimated residual variances for continuous outcomes;
  simfac* limit4*;

! Random intercept factor for binary outcome covariance;
  RandInt BY speed2@1 acc2@1;
  [RandInt@0]; ! Fix fixed intercept to 0;
   RandInt*;   ! Estimate random intercept variance;

MODEL CONSTRAINT:          ! Like ESTIMATE in SAS or LINCOM in STATA;
  NEW(DStoAcc);            ! List names of estimated effects on NEW;
  DStoAcc = sim7 * acc8;   ! Indirect effect of Dscan --> Sim --> Acc;
```

```
SUMMARY OF ANALYSIS
Number of groups                                                 1
Number of observations                                         114 → It used all cases for all equations

Number of Free Parameters                       40
Loglikelihood
          H0 Value                        -318.727
          H0 Scaling Correction Factor       0.9958
            for MLR
Information Criteria
          Akaike (AIC)                     717.455
          Bayesian (BIC)                   826.903
          Sample-Size Adjusted BIC         700.476
            (n* = (n + 2) / 24)
```

These are all the fit statistics we get—there is no saturated model or null model easily possible when not all variables are conditionally multivariate normal.

MODEL RESULTS

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value	
RANDINT BY					
SPEED2	1.000	0.000	999.000	999.000	
ACC2	1.000	0.000	999.000	999.000	
SIMFAC ON					
SEX	0.125	0.134	0.931	0.352	
AGE75	-0.005	0.017	-0.276	0.782	
VISFAC	-0.067	0.085	-0.785	0.433	
ZUFOV1	0.002	0.099	0.020	0.984	
ZUFOV2	**0.166**	**0.103**	**1.611**	**0.107**	**→ Was marginal, now not**
ZUFOV3	0.112	0.102	1.095	0.274	
DSCAN	**0.218**	**0.098**	**2.228**	**0.026**	**→ Also found in dissertation original sample**
LIMIT4 ON					
SEX	0.292	0.192	1.520	0.129	
AGE75	-0.002	0.023	-0.078	0.938	
VISFAC	0.013	0.102	0.127	0.899	
ZUFOV1	0.098	0.125	0.782	0.434	
ZUFOV2	0.150	0.125	1.204	0.229	
ZUFOV3	-0.154	0.134	-1.150	0.250	
DSCAN	0.138	0.128	1.076	0.282	
SIMFAC	0.018	0.150	0.122	0.903	
ACC2 ON					
SEX	-0.761	0.559	-1.361	0.174	
AGE75	0.059	0.083	0.711	0.477	
VISFAC	0.086	0.310	0.279	0.781	
ZUFOV1	-0.450	0.614	-0.733	0.463	
ZUFOV2	**-0.838**	**0.384**	**-2.178**	**0.029**	**→ New significant result given robust SEs**
ZUFOV3	-0.060	0.389	-0.155	0.877	
DSCAN	-0.458	0.324	-1.415	0.157	
SIMFAC	**1.461**	**0.543**	**2.692**	**0.007**	**→ Reason for the publication**
LIMIT4	-0.419	0.406	-1.033	0.302	
SPEED2 ON					
SEX	**-1.388**	**0.746**	**-1.862**	**0.063**	**→ Was p=.048, now NS with robust SEs**
AGE75	-0.064	0.052	-1.226	0.220	
VISFAC	-0.183	0.350	-0.523	0.601	
ZUFOV1	-0.478	0.485	-0.986	0.324	
ZUFOV2	-0.286	0.607	-0.471	0.638	
ZUFOV3	**-1.143**	**0.375**	**-3.045**	**0.002**	**→ Also reported significant in publication**
DSCAN	**0.964**	**0.516**	**1.869**	**0.062**	**→ Also reported marginal in publication**
SIMFAC	-0.346	0.692	-0.500	0.617	
LIMIT4	-0.353	0.486	-0.726	0.468	
Means					
RANDINT	0.000	0.000	999.000	999.000	
Intercepts					
SIMFAC	-0.082	0.103	-0.794	0.427	
LIMIT4	0.075	0.150	0.502	0.616	
Thresholds					
SPEED2$1	1.738	0.511	3.399	0.001	
ACC2$1	2.050	0.533	3.843	0.000	
Variances					
RANDINT	0.049	0.005	9.158	0.000	→ Not included in publication model (should have)
Residual Variances					
SIMFAC	0.465	0.061	7.598	0.000	
LIMIT4	0.850	0.114	7.481	0.000	
New/Additional Parameters					
DSTOACC	0.319	0.175	1.824	0.068	→ Not tested for publication (just for demo here)

LOGISTIC REGRESSION ODDS RATIO RESULTS

	Estimate	S.E.	(Est. - 1) / S.E.	Two-Tailed P-Value
ACC2 ON				
SEX	0.467	0.261	-2.040	0.041
AGE75	1.061	0.088	0.690	0.490
VISFAC	1.090	0.337	0.267	0.790
ZUFOV1	0.638	0.391	-0.926	0.354
ZUFOV2	0.433	0.166	-3.409	0.001
ZUFOV3	0.942	0.367	-0.160	0.873
DSCAN	0.633	0.205	-1.795	0.073
SIMFAC	4.309	2.338	1.415	0.157
LIMIT4	0.658	0.267	-1.283	0.199
SPEED2 ON				
SEX	0.250	0.186	-4.032	0.000
AGE75	0.938	0.049	-1.266	0.205
VISFAC	0.833	0.292	-0.574	0.566

```
    ZUFOV1            0.620      0.301     -1.265      0.206
    ZUFOV2            0.751      0.456     -0.546      0.585
    ZUFOV3            0.319      0.120     -5.692      0.000
    DSCAN             2.622      1.352      1.199      0.230
    SIMFAC            0.708      0.489     -0.598      0.550
    LIMIT4            0.703      0.341     -0.871      0.384
```

STATA GSEM Syntax and Partial Output for Path Model with Random Intercept:

```
display "STATA Path Model for Example 6b"
display "Results do not match Mplus because of missing data"
gsem                                                ///
(speed2@1 acc2@1 <-RandInt)                         /// Random intercept factor for binary outcome covariance
(simfac limit4 speed2 acc2 RandInt@0 <- _cons)      /// All outcome intercepts estimated by default
(simfac <- sex age75 visfac zufov1 zufov2 zufov3 dscan)                  /// X1-X7 to normal M1
(limit4 <- sex age75 visfac zufov1 zufov2 zufov3 dscan simfac)           /// X1-X7, M1    to normal M2
(acc2   <- sex age75 visfac zufov1 zufov2 zufov3 dscan simfac limit4, logit)   /// X1-X7, M1-M2 to binary Y1
(speed2 <- sex age75 visfac zufov1 zufov2 zufov3 dscan simfac limit4, logit),  /// X1-X7, M1-M2 to binary Y2
var(e.simfac e.limit4 e.RandInt)          /// All residual variances estimated (by default)
method(ml) vce(robust)                    // Equation-wise ML, robust SEs
gsem, coeflegend                          // Print parameter labels, too (to use in lincom)
nlcom _b[simfac:dscan]*_b[acc2:simfac]    // Indirect effect: dscan --> sim --> acc
estat eform speed2 acc2                   // Get odds ratios for binary outcomes

Generalized structural equation model           Number of obs     =         97 → Number of complete cases

Response       : speed2                         Number of obs     =         94
Family         : Bernoulli
Link           : logit

Response       : acc2                           Number of obs     =         95
Family         : Bernoulli
Link           : logit

Response       : simfac                         Number of obs     =         97
Family         : Gaussian
Link           : identity

Response       : limit4                         Number of obs     =         95
Family         : Gaussian
Link           : identity

Log pseudolikelihood =  -279.9549
 ( 1)  [speed2]RandInt = 1
 ( 2)  [acc2]RandInt = 1
------------------------------------------------------------------------------
             |               Robust
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
speed2       |
         sex |  -1.557061   .7879778    -1.98   0.048    -3.101469   -.0126527
       age75 |  -.0546159   .0525276    -1.04   0.298    -.1575682    .0483363
      visfac |  -.1502138   .3466184    -0.43   0.665    -.8295735    .5291458
      zufov1 |  -.5356348   .4797669    -1.12   0.264    -1.475961     .404691
      zufov2 |  -.3621424   .5854344    -0.62   0.536    -1.509573    .7852879
      zufov3 |  -1.123434   .3804918    -2.95   0.003    -1.869185   -.3776841
       dscan |   1.072291   .5491541     1.95   0.051    -.0040308    2.148614
      simfac |  -.2707209    .683736    -0.40   0.692    -1.610819    1.069377
      limit4 |  -.3472816   .4811235    -0.72   0.470    -1.290266    .5957032
    RandInt  |          1  (constrained)
       _cons |  -1.441395   .4920703    -2.93   0.003    -2.405836   -.4769553 → intercept, not threshold
-------------+----------------------------------------------------------------
acc2         |
         sex |  -.7558821     .68301    -1.11   0.268    -2.094557    .5827929
       age75 |  -.1174961   .0851259    -1.38   0.168    -.2843399    .0493477
      visfac |   .4131037   .2933547     1.41   0.159    -.1618609    .9880684
      zufov1 |  -1.670182   1.457019    -1.15   0.252    -4.525887    1.185524
      zufov2 |  -.7274938   .3456611    -2.10   0.035    -1.404977   -.0500106
      zufov3 |  -.0820221   .5071776    -0.16   0.872    -1.076072    .9120277
       dscan |  -.5146463   .3802142    -1.35   0.176    -1.259852    .2305598
      simfac |   1.795184   .8688706     2.07   0.039     .0922286    3.498139
      limit4 |  -.9255547   .6167973    -1.50   0.133    -2.134455    .2833457
    RandInt  |          1  (constrained)
       _cons |  -3.091845   1.068584    -2.89   0.004     -5.18623   -.9974596 → intercept, not threshold
-------------+----------------------------------------------------------------
```

```
simfac         |
           sex |   .1274706    .137288     0.93   0.353    -.1416089    .3965501
         age75 |  -.0081964   .0166646    -0.49   0.623    -.0408585    .0244656
        visfac |  -.0621605   .0869903    -0.71   0.475    -.2326583    .1083373
        zufov1 |   .0095013   .1016697     0.09   0.926    -.1897675    .2087702
        zufov2 |    .180878   .1035175     1.75   0.081    -.0220126    .3837687
        zufov3 |   .1043617   .1018883     1.02   0.306    -.0953357    .3040592
         dscan |   .2191596   .0996074     2.20   0.028     .0239328    .4143865
         _cons |  -.0972922   .1053367    -0.92   0.356    -.3037482    .1091639
---------------+------------------------------------------------------------------
limit4         |
        simfac |   .0179388   .1506128     0.12   0.905    -.2772568    .3131344
           sex |   .1759188   .2057114     0.86   0.392    -.2272682    .5791057
         age75 |  -.0034281   .0230333    -0.15   0.882    -.0485726    .0417163
        visfac |   .0148541   .1110292     0.13   0.894    -.2027591    .2324674
        zufov1 |   .1181027    .131899     0.90   0.371    -.1404145    .3766199
        zufov2 |   .1511188    .134478     1.12   0.261    -.1124532    .4146907
        zufov3 |  -.1373689   .1355998    -1.01   0.311    -.4031396    .1284018
         dscan |   .2287724   .1315016     1.74   0.082    -.0289659    .4865108
         _cons |   .1419225   .1618459     0.88   0.381    -.1752896    .4591347
---------------+------------------------------------------------------------------
 var(e.RandInt)|   3.31e-34   5.77e-33                      4.77e-49    2.29e-19
---------------+------------------------------------------------------------------
  var(e.simfac)|   .4618696   .0610618                      .3564394    .5984847
  var(e.limit4)|   .8334947   .1121721                      .6402473     1.08507
------------------------------------------------------------------------------

. nlcom _b[simfac:dscan]*_b[acc2:simfac]      // Indirect effect: dscan --> sim --> acc
       _nl_1:  _b[simfac:dscan]*_b[acc2:simfac]
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _nl_1 |   .3934318   .2507519     1.57   0.117    -.0980329    .8848964
------------------------------------------------------------------------------

. estat eform speed2 acc2                     // Get odds ratios for binary outcomes
------------------------------------------------------------------------------
               |                Robust
               |     exp(b)   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+--------------------------------------------------------------
speed2         |
           sex |   .2107546     .16607    -1.98   0.048     .0449831     .987427
         age75 |   .9468487   .0497357    -1.04   0.298     .8542186    1.049524
        visfac |   .8605239   .2982735    -0.43   0.665     .4362353    1.697482
        zufov1 |   .5852976   .2808064    -1.12   0.264     .2285591    1.498839
        zufov2 |   .6961832   .4075696    -0.62   0.536     .2210044    2.193038
        zufov3 |   .3251612   .1237212    -2.95   0.003     .1542494     .685447
         dscan |   2.922067   1.604665     1.95   0.051     .9959773    8.572964
        simfac |   .7628294   .5215739    -0.40   0.692      .199724    2.913564
        limit4 |   .7066063   .3399649    -0.72   0.470     .2751975    1.814306
       RandInt |   2.718282  (constrained)
         _cons |   .2365974   .1164226    -2.93   0.003     .0901901    .6206703
---------------+--------------------------------------------------------------
acc2           |
           sex |   .4695962   .3207389    -1.11   0.268     .1231248    1.791034
         age75 |    .889144   .0756892    -1.38   0.168     .7525109    1.050586
        visfac |   1.511502   .4434062     1.41   0.159     .8505595    2.686041
        zufov1 |   .1882128   .2742297    -1.15   0.252     .0108251      3.2724
        zufov2 |   .4831182   .1669952    -2.10   0.035     .2453727    .9512193
        zufov3 |   .9212516   .4672382    -0.16   0.872     .3409321    2.489365
         dscan |   .5977119   .2272586    -1.35   0.176     .2836959    1.259305
        simfac |   6.020581   5.231106     2.07   0.039     1.096616    33.05388
        limit4 |   .3963115   .2444439    -1.50   0.133      .118309    1.327564
       RandInt |   2.718282  (constrained)
         _cons |   .0454181    .048533    -2.89   0.004     .0055931    .3688152
------------------------------------------------------------------------------
```

For a sample results section, please see the original manuscript, with the following addition:

A residual covariance between the two binary outcomes was created using a random intercept latent factor, in which the factor loadings to each binary outcome were fixed to 1 for identification, the latent factor mean was fixed to 0 for identification, and the latent factor variance was estimated.