Competing Risk Analysis

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Abstract:

Competing risks arise in studies when subjects are exposed to more than one cause of event and event due to one cause excludes event due to other causes. If we want real world probabilities of events and separate the probability of event into different causes, competing risks methodology should be used as opposed to standard survival analysis methods. The traditional analysis for competing risks is to perform a separate analysis for each event type, treating other events as censoring (cause-specific approach). The biggest drawback of cause-specific analysis is the requirement that times for different event types be independent, which is often not the case. Although cause-specific approach can give cause-specific hazards, it could not provide actual probability of event. Recently, cumulative incidence function (CIF) and its following sub-distribution approach have been developed to overcome the above two problems by accounting for competing risks. CIF is useful in estimating the probabilities of events, but we cannot examine covariate effects on the CIF. Sub-distribution approach allows us to test covariate effects on the CIF, but sub-distribution hazards are difficult to interpret and so should be used with caution. In summary, the currently available approaches for competing risks have their own advantages and disadvantages. How to analyze compete risks correctly depends on the aim of study and the characteristics of event types.

Reference (selected)

1. Paul D. Alison. Survival Analysis using SAS a practical guide. Second edition. 2010.
2. Sally R. Hinchlie, Competing Risks - What, Why, When and How? http://www2.le.ac.uk/departments/health-sciences/research/biostats/youngsurv/pdf/SHinchliffe.pdf
3. Scrucca L, Santucci A, Aversa F. Competing risk analysis using R: an easy guide for clinicians. Bone Marrow Transplant. 2007 Aug;40(4):381-7. 2007.
4. Pawel Paczuski. Nonparametric summary curves for competing risks in R. http://www-personal.umich.edu/~pbpacz/dat/stat/CompetingRisksInR.pdf
5. Melania Pintilie. Landmarks in the analysis of Competing risks.
6. Guixian Lin, Ying So. et al. Analyzing Survival Data with Competing Risks Using SAS® Software. SAS Global Forum. 2012.
7. Fine, J. P., & Gray, R.J. A proportional hazards model for the subdistribution of a competing risk. Journal of the American Statistical Association, 94(446), 496-509. 1999.

Appendix I:

SAS codes: (Page 3-14)

```
/* Data described in Chapter 6 of P. D. Allison, "SAS System for
   Survival Analysis: A Practical Guide."                          */

/* Data input */
data leaders;
input years lost manner start military age conflict loginc growth
  pop land literacy region;
cards;
3 2 1 975 0 53 1 5.7990926545 -5.7 8 1247 20 1
8 0 0 979 0 37 1 5.7990926545 -5.7 8 1247 20 1
3 3 0 960 0 44 1 4.7004803658 1 4 112 11 1
1 3 0 964 0 51 1 4.7004803658 1 4 112 11 1
1 3 1 965 1 56 1 4.7004803658 1 4 112 11 1
0 3 1 967 1 37 1 4.7004803658 1 4 112 11 1
1 3 1 968 0 50 1 4.7004803658 1 4 112 11 1
15 0 1 972 1 39 1 4.7004803658 1 4 112 11 1
13 2 0 966 0 45 0 5.4380793089 8.5 1.2 600 30 1
7 0 0 980 0 55 0 5.4380793089 8.5 1.2 600 30 1
3 3 0 962 0 50 1 4.3820266347 2.1 5.2 28 30 1
0 3 1 966 0 19 1 4.3820266347 2.1 5.2 28 30 1
9 3 1 966 1 26 1 4.3820266347 2.1 5.2 28 30 1
10 3 1 976 1 30 1 4.3820266347 2.1 5.2 28 30 1
0 0 1 987 1 38 1 4.3820266347 2.1 5.2 28 30 1
22 1 0 960 0 36 1 5.5214609179 2.7 11 475 65 1
5 0 0 982 0 49 1 5.5214609179 2.7 11 475 65 1
12 0 0 975 0 51 1 5.0751738152 2.4 0.4 4 37 1
5 3 0 960 0 30 0 5.0751738152 0.1 2.7 623 20 1
13 3 1 965 1 44 0 5.0751738152 0.1 2.7 623 20 1
6 0 1 981 1 45 0 5.0751738152 0.1 2.7 623 20 1
15 3 0 960 0 42 1 4.3820266347 -5.8 5 1284 17 1
3 3 1 975 1 43 1 4.3820266347 -5.8 5 1284 17 1
3 3 0 979 0 35 1 4.3820266347 -5.8 5 1284 17 1
5 0 1 982 1 40 1 4.3820266347 -5.8 5 1284 17 1
2 3 0 972 0 53 0 5.1929568509 -0.6 0.43 2.1 15 1
0 1 1 975 0 . 0 5.1929568509 -0.6 0.43 2.1 15 1
2 3 0 976 0 38 0 5.1929568509 -0.6 0.43 2.1 15 1
3 1 0 960 0 43 1 5.8289456176 3.5 2.1 342 80 1
4 3 1 963 0 42 1 5.8289456176 3.5 2.1 342 80 1
8 3 1 968 1 30 1 5.8289456176 3.5 2.1 342 80 1
1 3 1 977 1 38 1 5.8289456176 3.5 2.1 342 80 1
7 0 0 979 1 36 1 5.8289456176 3.5 2.1 342 80 1
9 0 0 977 0 61 1 7.6778635007 -3.6 0.32 22 20 1
10 3 1 968 0 44 1 5.7990926545 -1.3 0.35 28 55 1
8 0 1 979 1 37 1 5.7990926545 -1.3 0.35 28 55 1
2 3 1 974 1 53 1 4.4998096703 0.5 48 1221 35 1
10 0 1 977 1 42 1 4.4998096703 0.5 48 1221 35 1
7 2 0 960 0 58 0 7.1777824162 3.2 1 267 65 1
19 0 1 967 0 32 0 7.1777824162 3.2 1 267 65 1
22 0 0 965 0 41 0 4.8675344505 1.4 0.8 11 12 1
3 3 1 966 1 51 1 5.7037824747 -2.1 14 238 30 1
2 3 0 969 0 56 1 5.7037824747 -2.1 14 238 30 1
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1 3 0 970 0 64 1 5.7037824747 -2.1 14 238 30 1
6 3 1 972 1 41 1 5.7037824747 -2.1 14 238 30 1
0 3 1 978 1 41 1 5.7037824747 -2.1 14 238 30 1
2 3 0 979 0 45 1 5.7037824747 -2.1 14 238 30 1
5 0 1 981 1 34 1 5.7037824747 -2.1 14 238 30 1
0 3 0 984 1 61 1 4.7004803658 1.1 7 245 20 1
3 0 1 984 1 61 1 4.7004803658 1.1 7 245 20 1
6 3 1 974 0 43 1 4.9416424226 2.4 1 36 9 1
6 0 1 980 1 41 1 4.9416424226 2.4 1 36 9 1
27 0 0 960 0 55 0 5.9401712527 1 11 322 24 1
14 2 0 963 0 74 1 5.1357984371 2.3 23 583 47 1
9 0 0 978 0 54 1 5.1357984371 2.3 23 583 47 1
19 3 0 966 0 52 0 4.605170186 6.3 1.6 30 65 1
1 0 1 986 1 . 0 4.605170186 6.3 1.6 30 65 1
8 3 0 971 0 58 1 5.7365722975 0.8 2.5 111 20 1
7 0 1 980 1 28 1 5.7365722975 0.8 2.5 111 20 1
11 3 0 960 0 48 1 5.0106352941 -1.2 11 587 53 1
2 3 0 972 1 62 1 5.0106352941 -1.2 11 587 53 1
12 0 0 975 1 39 1 5.0106352941 -1.2 11 587 53 1
23 0 0 964 0 58 1 4.7004803658 2.2 7.7 118 25 1
8 3 0 960 0 45 0 4.248495242 1.2 8.7 1240 10 1
19 0 1 968 1 32 0 4.248495242 1.2 8.7 1240 10 1
17 3 0 960 0 36 1 5.2983173665 0.3 2 1030 17 1
0 3 1 978 1 42 1 5.2983173665 0.3 2 1030 17 1
0 3 1 979 1 36 1 5.2983173665 0.3 2 1030 17 1
4 3 1 980 1 40 1 5.2983173665 0.3 2 1030 17 1
2 0 1 984 1 39 1 5.2983173665 0.3 2 1030 17 1
14 1 0 968 0 68 1 6.0161571597 2.8 1 1.9 79 1
5 0 0 982 0 52 1 6.0161571597 2.8 1 1.9 79 1
11 2 1 975 1 42 1 5.1357984371 0.1 15 801 14 1
0 0 0 986 1 47 1 5.1357984371 0.1 15 801 14 1
13 3 0 960 0 44 0 4.605170186 -1.2 7 1267 8 1
13 0 1 974 1 43 0 4.605170186 -1.2 7 1267 8 1
5 3 0 960 0 48 1 5.3471075307 3.2 112 923 30 1
0 3 1 966 1 42 1 5.3471075307 3.2 112 923 30 1
9 3 1 966 1 32 1 5.3471075307 3.2 112 923 30 1
0 3 1 975 1 38 1 5.3471075307 3.2 112 923 30 1
3 1 1 976 1 39 1 5.3471075307 3.2 112 923 30 1
4 3 0 979 0 54 1 5.3471075307 3.2 112 923 30 1
1 3 1 983 1 41 1 5.3471075307 3.2 112 923 30 1
2 0 1 985 1 44 1 5.3471075307 3.2 112 923 30 1
11 3 0 962 0 38 1 4.248495242 2.3 7 26 37 1
14 0 1 973 1 33 1 4.248495242 2.3 7 26 37 1
12 0 1 975 1 38 0 6.1944053911 -1.3 0.11 1 50 1
20 1 0 960 0 54 1 5.5214609179 -0.5 7.3 196 10 1
6 0 0 981 0 46 1 5.5214609179 -0.5 7.3 196 10 1
0 3 0 976 0 37 0 6.4134589572 3.4 0.07 0.5 60 1
10 0 1 977 0 42 0 6.4134589572 3.4 0.07 0.5 60 1
3 2 0 961 0 65 1 5.0751738152 1.1 4 72 15 1
2 1 0 964 0 54 1 5.0751738152 1.1 4 72 15 1
0 3 1 967 1 45 1 5.0751738152 1.1 4 72 15 1
1 3 1 967 1 36 1 5.0751738152 1.1 4 72 15 1
17 1 0 968 0 63 1 5.0751738152 1.1 4 72 15 1
2 0 0 985 1 48 1 5.0751738152 1.1 4 72 15 1
3 1 0 960 0 41 0 4.3820266347 -0.8 8 638 60 1
3 1 0 964 0 40 0 4.3820266347 -0.8 8 638 60 1
18 0 1 969 1 48 0 4.3820266347 -0.8 8 638 60 1
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12 1 0 966 0 46 1 6.9565454432 1.6 35 1221 65 1
9 0 0 978 0 62 1 6.9565454432 1.6 35 1221 65 1
14 2 0 968 0 69 1 5.7990926545 2.6 0.7 17 65 1
2 3 1 961 0 37 1 5.7990926545 2.6 0.7 17 65 1
1 0 0 986 0 18 1 5.7990926545 2.6 0.7 17 65 1
24 1 0 961 0 39 0 4.8675344505 0.9 24 945 79 1
2 0 0 985 0 60 0 4.8675344505 0.9 24 945 79 1
2 3 0 960 0 58 1 5.1929568509 1.1 3.3 57 18 1
3 3 1 963 0 50 1 5.1929568509 1.1 3.3 57 18 1
20 0 1 967 1 30 1 5.1929568509 1.1 3.3 57 18 1
8 3 0 962 0 37 1 5.0106352941 -4.4 16 236 52 1
8 3 1 971 1 46 1 5.0106352941 -4.4 16 236 52 1
0 3 1 979 0 67 1 5.0106352941 -4.4 16 236 52 1
0 3 0 979 0 59 1 5.0106352941 -4.4 16 236 52 1
0 3 1 985 1 72 1 5.0106352941 -4.4 16 236 52 1
0 0 1 986 1 43 1 5.0106352941 -4.4 16 236 52 1
5 3 0 960 0 39 1 4.248495242 1.4 8.5 274 7 1
14 3 1 966 1 50 1 4.248495242 1.4 8.5 274 7 1
1 3 1 980 1 48 1 4.248495242 1.4 8.5 274 7 1
0 3 1 982 1 44 1 4.248495242 1.4 8.5 274 7 1
4 3 1 983 1 34 1 4.248495242 1.4 8.5 274 7 1
0 0 1 987 1 38 1 4.248495242 1.4 8.5 274 7 1
5 3 0 960 0 43 1 4.248495242 -1.3 33 2345 40 1
1 3 0 960 0 35 1 4.248495242 -1.3 33 2345 40 1
0 1 1 960 1 30 1 4.248495242 -1.3 33 2345 40 1
0 3 1 960 0 42 1 4.248495242 -1.3 33 2345 40 1
2 3 1 961 0 40 1 4.248495242 -1.3 33 2345 40 1
1 3 0 960 0 35 1 4.248495242 -1.3 33 2345 40 1
1 3 1 964 0 45 1 4.248495242 -1.3 33 2345 40 1
0 3 0 965 0 39 1 4.248495242 -1.3 33 2345 40 1
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0 3 0 963 0 33 0 4.8675344505 0.9 0.01 2.4 79 1
0 1 1 964 0 59 0 4.8675344505 0.9 0.01 2.4 79 1
7 0 0 980 0 56 1 6.0637852087 1.5 9.7 391 50 1
2 3 0 962 0 43 1 6.3456363608 3.6 24 2381 52 0
12 2 1 965 1 40 1 6.3456363608 3.6 24 2381 52 0
8 0 0 979 1 50 1 6.3456363608 3.6 24 2381 52 0
16 0 0 971 0 38 1 7.668561108 2.1 0.5 0.6 40 0
11 3 0 970 1 52 1 5.5214609179 4.2 53 1001 45 0
6 0 0 981 1 53 1 5.5214609179 4.2 53 1001 45 0
8 0 1 979 0 79 1 6.7684932116 4.2 51 1648 48 0
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2 3 0 966 0 50 1 6.7452363495 7.6 18 435 55 0
11 1 1 968 1 56 1 6.7452363495 7.6 18 435 55 0
8 0 0 979 1 42 1 6.7452363495 7.6 18 435 55 0
6 2 0 963 0 68 1 8.0096953577 2.9 4.3 20 80 0
5 1 0 969 0 71 1 8.0096953577 2.9 4.3 20 80 0
3 1 0 974 0 52 1 8.0096953577 2.9 4.3 20 80 0
0 1 0 979 0 56 1 8.0096953577 2.9 4.3 20 80 0
4 1 0 979 0 66 1 8.0096953577 2.9 4.3 20 80 0
0 1 0 983 0 68 1 8.0096953577 2.9 4.3 20 80 0
4 2 0 961 0 66 0 9.3968199389 0.2 2 18 71 0
12 2 0 965 0 51 0 9.3968199389 0.2 2 18 71 0
10 0 0 977 0 47 0 9.3968199389 0.2 2 18 71 0
6 1 0 964 0 53 1 6.8458798753 -6 2.7 10 75 0
6 1 0 970 0 60 1 6.8458798753 -6 2.7 10 75 0
6 1 0 976 0 52 1 6.8458798753 -6 2.7 10 75 0
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0 3 0 982 0 34 1 6.8458798753 -6 2.7 10 75 0
5 0 0 982 0 40 1 6.8458798753 -6 2.7 10 75 0
18 0 1 969 1 27 0 8.1690531499 -0.9 4 1760 55 0
26 0 0 961 0 32 1 5.7683209958 2.9 25 447 28 0
17 0 0 970 0 30 1 6.7334018918 6.5 1.3 212 20 0
1 3 0 971 0 54 0 9.3413686344 -7 0.3 11 40 0
15 0 0 972 0 35 0 9.3413686344 -7 0.3 11 40 0
11 3 0 964 0 19 0 7.383989458 6.7 15 2149 52 0
7 2 0 975 0 61 0 7.383989458 6.7 15 2149 52 0
5 0 0 982 0 32 0 7.383989458 6.7 15 2149 52 0
1 1 0 965 0 57 1 4.8675344505 1.3 24 2506 20 0
0 1 0 966 0 30 1 4.8675344505 1.3 24 2506 20 0
16 3 1 969 1 39 1 4.8675344505 1.3 24 2506 20 0
0 3 1 961 0 47 1 5.9914645471 4.9 12 185 47 0
0 3 1 961 1 . 1 5.9914645471 4.9 12 185 47 0
1 3 0 961 0 55 1 5.9914645471 4.9 12 185 47 0
0 1 1 962 1 . 1 5.9914645471 4.9 12 185 47 0
0 3 1 963 1 37 1 5.9914645471 4.9 12 185 47 0
3 3 1 963 1 52 1 5.9914645471 4.9 12 185 47 0
4 3 0 966 1 37 1 5.9914645471 4.9 12 185 47 0
17 0 1 970 1 42 1 5.9914645471 4.9 12 185 47 0
0 0 1 987 1 51 1 6.1312264895 5 8 164 62 0
1 1 1 960 1 65 0 6.3969296552 3 54 781 70 0
6 3 0 965 0 41 0 6.3969296552 3 54 781 70 0
2 1 1 971 1 71 0 6.3969296552 3 54 781 70 0
0 1 0 974 0 48 0 6.3969296552 3 54 781 70 0
0 1 0 974 0 70 0 6.3969296552 3 54 781 70 0
4 1 1 979 1 61 0 6.3969296552 3 54 781 70 0
4 0 0 983 0 56 0 6.3969296552 3 54 781 70 0
1 3 0 961 0 33 1 5.5214609179 5.7 6.7 195 15 0
5 3 1 962 1 45 1 5.5214609179 5.7 6.7 195 15 0
7 3 0 967 0 32 1 5.5214609179 5.7 6.7 195 15 0
3 3 1 974 1 29 1 5.5214609179 5.7 6.7 195 15 0
1 3 0 977 1 . 1 5.5214609179 5.7 6.7 195 15 0
9 0 1 978 1 36 1 5.5214609179 5.7 6.7 195 15 0
2 3 0 967 0 . 0 5.6347896032 6 2.4 333 25 0
7 3 0 971 0 37 0 5.6347896032 6 2.4 333 25 0
0 1 1 978 0 . 0 5.6347896032 6 2.4 333 25 0
2 1 0 978 0 41 0 5.6347896032 6 2.4 333 25 0
6 3 0 980 0 41 0 5.6347896032 6 2.4 333 25 0
1 0 1 986 0 47 0 5.6347896032 6 2.4 333 25 0
16 0 0 971 0 55 0 9.5460980677 -1.2 2 84 68 0
10 3 1 963 0 43 1 4.4998096703 0.5 14 648 12 2
0 3 1 978 0 61 1 4.4998096703 0.5 14 648 12 2
0 3 0 979 0 50 1 4.4998096703 0.5 14 648 12 2
7 3 1 979 0 50 1 4.4998096703 0.5 14 648 12 2
1 0 1 986 1 39 1 4.4998096703 0.5 14 648 12 2
3 3 0 971 0 51 1 4.3820266347 0.5 109 144 29 2
0 3 1 975 0 56 1 4.3820266347 0.5 109 144 29 2
0 3 1 975 1 . 1 4.3820266347 0.5 109 144 29 2
2 3 1 975 0 59 1 4.3820266347 0.5 109 144 29 2
3 3 1 978 1 42 1 4.3820266347 0.5 109 144 29 2
0 3 0 981 0 75 1 4.3820266347 0.5 109 144 29 2
5 0 1 982 1 52 1 4.3820266347 0.5 109 144 29 2
15 0 0 972 0 17 0 4.248495242 0.1 1.5 47 5 2
20 0 0 967 0 22 0 9.3413686344 7.4 0.3 6 45 2
1 1 0 976 0 56 1 4.7874917428 4.4 1088 9596 75 2
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9 0 0 978 0 74 1 4.7874917428 4.4 1088 9596 75 2
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0 3 0 987 0 52 1 6.4769723629 3.4 0.74 18 80 2
0 1 1 987 1 38 1 6.4769723629 3.4 0.74 18 80 2
0 3 0 987 0 69 1 6.4769723629 3.4 0.74 18 80 2
4 1 0 960 0 61 0 8.1969879273 4.8 122 372 99 2
8 1 0 964 0 63 0 8.1969879273 4.8 122 372 99 2
2 1 0 972 0 54 0 8.1969879273 4.8 122 372 99 2
2 1 0 974 0 67 0 8.1969879273 4.8 122 372 99 2
2 1 0 976 0 71 0 8.1969879273 4.8 122 372 99 2
2 2 0 978 0 68 0 8.1969879273 4.8 122 372 99 2
2 1 0 980 0 69 0 8.1969879273 4.8 122 372 99 2
5 1 0 982 0 65 0 8.1969879273 4.8 122 372 99 2
0 0 0 987 0 63 0 8.1969879273 4.8 122 372 99 2
1 2 0 964 0 60 1 4.7874917428 1.5 816 3288 36 2
11 1 0 966 0 49 1 4.7874917428 1.5 816 3288 36 2
2 1 0 977 0 81 1 4.7874917428 1.5 816 3288 36 2
0 1 0 979 0 77 1 4.7874917428 1.5 816 3288 36 2
3 0 0 984 0 40 1 4.7874917428 1.5 816 3288 36 2
21 0 1 966 1 46 1 4.8675344505 5 184 1919 62 2
5 3 1 970 1 57 0 4.248495242 -6.8 7 181 48 2
3 0 1 975 0 47 0 4.248495242 -6.8 7 181 48 2
8 0 1 979 1 44 0 4.248495242 -6.8 7 181 48 2
3 1 0 979 0 29 1 5.8141305318 1.3 0.01 0.7 90 2
0 1 0 982 0 . 1 5.8141305318 1.3 0.01 0.7 90 2
0 1 1 960 0 64 1 5.9914645471 6.7 43 98 95 2
0 1 0 960 0 63 1 5.9914645471 6.7 43 98 95 2
18 3 0 961 0 60 1 5.9914645471 6.7 43 98 95 2
0 1 0 979 0 60 1 5.9914645471 6.7 43 98 95 2
8 0 1 979 1 48 1 5.9914645471 6.7 43 98 95 2
1 1 1 960 0 48 1 4.0943445622 3.1 4 236 85 2
1 1 1 964 1 . 1 4.0943445622 3.1 4 236 85 2
12 0 1 975 0 55 1 4.0943445622 3.1 4 236 85 2
5 2 0 970 0 48 1 6.3456363608 4.5 16 330 65 2
5 1 0 976 0 51 1 6.3456363608 4.5 16 330 65 2
6 0 0 981 0 55 1 6.3456363608 4.5 16 330 65 2
13 3 1 965 0 39 0 4.7874917428 1.4 0.2 0.3 36 2
9 0 1 978 0 38 0 4.7874917428 1.4 0.2 0.3 36 2
3 0 0 984 0 58 1 6.7569323892 3.6 2 1565 80 2
8 1 0 968 0 45 0 5.8141305318 1.3 0.008 0.02 99 2
2 1 0 976 0 30 0 5.8141305318 1.3 0.008 0.02 99 2
0 1 0 978 0 55 0 5.8141305318 1.3 0.008 0.02 99 2
0 1 0 986 0 . 0 5.8141305318 1.3 0.008 0.02 99 2
15 0 0 972 0 37 1 4.4998096703 0.1 18 140 20 2
5 1 0 975 0 39 0 6.0161571597 0.9 3.6 461 32 2
2 1 0 980 0 40 0 6.0161571597 0.9 3.6 461 32 2
2 0 0 985 0 34 0 6.0161571597 0.9 3.6 461 32 2
2 1 0 969 1 52 1 4.7874917428 2.5 107 803 26 2
5 3 0 971 0 43 1 4.7874917428 2.5 107 803 26 2
10 0 1 977 1 53 1 4.7874917428 2.5 107 803 26 2
4 1 0 961 0 51 1 5.6347896032 2.9 63 300 88 2
20 1 0 965 0 48 1 5.6347896032 2.9 63 300 88 2
1 0 1 986 0 53 1 5.6347896032 2.9 63 300 88 2
24 0 0 963 0 40 0 7.5120712458 7.8 2.6 0.6 86 2
3 1 0 978 0 35 1 5.8141305318 1.3 0.3 28 60 2
3 1 0 981 0 38 1 5.8141305318 1.3 0.3 28 60 2
1 0 0 986 0 . 1 5.8141305318 1.3 0.3 28 60 2
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10 0 0 977 0 71 1 4.7874917428 2.9 17 66 87 2
12 0 0 975 1 65 1 6.492239835 4.6 20 35 94 2
10 1 0 963 1 52 1 5.598421959 4.3 54 514 82 2
1 1 0 973 0 66 1 5.598421959 4.3 54 514 82 2
0 1 0 975 0 70 1 5.598421959 4.3 54 514 82 2
1 1 0 975 0 64 1 5.598421959 4.3 54 514 82 2
1 3 1 976 1 . 1 5.598421959 4.3 54 514 82 2
2 3 1 977 1 60 1 5.598421959 4.3 54 514 82 2
7 0 0 980 1 60 1 5.598421959 4.3 54 514 82 2
22 0 0 965 0 47 0 5.8141305318 1.3 0.1 0.7 95 2
3 1 0 978 0 36 0 5.8141305318 1.3 0.08 0.03 45 2
6 1 0 981 0 . 0 5.8141305318 1.3 0.08 0.03 45 2
8 0 0 979 0 45 1 5.8141305318 1.3 0.08 0.03 45 2
17 2 0 969 0 61 1 4.248495242 -6 65 330 78 2
0 1 0 986 0 79 1 4.248495242 -6 65 330 78 2
1 0 0 986 0 73 1 4.248495242 -6 65 330 78 2
0 3 1 963 1 47 1 5.0751738152 -3 65 330 78 2
1 3 1 964 1 37 1 5.0751738152 -3 65 330 78 2
0 3 1 965 0 62 1 5.0751738152 -3 65 330 78 2
0 3 1 965 1 38 1 5.0751738152 -3 65 330 78 2
10 3 1 965 1 42 1 5.0751738152 -3 65 330 78 2
8 1 0 962 0 41 0 5.8579331545 1.3 0.18 2.9 90 2
3 1 0 970 0 48 0 5.8579331545 1.3 0.18 2.9 90 2
6 1 0 976 0 58 0 5.8579331545 1.3 0.18 2.9 90 2
0 1 0 982 0 . 0 5.8579331545 1.3 0.18 2.9 90 2
3 1 0 982 0 58 0 5.8579331545 1.3 0.18 2.9 90 2
6 0 0 981 0 70 0 6.6066501862 -0.4 0.08 0.44 90 3
1 1 0 962 0 52 0 7.4024515208 0.5 30.5 2767 94 3
3 3 0 963 0 63 0 7.4024515208 0.5 30.5 2767 94 3
4 3 1 966 1 52 0 7.4024515208 0.5 30.5 2767 94 3
0 3 1 970 1 50 0 7.4024515208 0.5 30.5 2767 94 3
2 1 1 971 1 53 0 7.4024515208 0.5 30.5 2767 94 3
0 1 0 973 0 57 0 7.4024515208 0.5 30.5 2767 94 3
2 3 0 974 0 43 0 7.4024515208 0.5 30.5 2767 94 3
4 1 1 976 1 51 0 7.4024515208 0.5 30.5 2767 94 3
1 1 0 980 1 55 0 7.4024515208 0.5 30.5 2767 94 3
0 1 0 981 1 54 0 7.4024515208 0.5 30.5 2767 94 3
1 1 0 982 0 54 0 7.4024515208 0.5 30.5 2767 94 3
4 0 0 983 0 58 0 7.4024515208 0.5 30.5 2767 94 3
20 0 0 967 0 36 0 8.1047034684 -1.8 0.23 14 95 3
10 1 0 966 0 46 0 6.907755279 3.8 0.25 0.43 99 3
9 2 0 976 0 44 0 6.907755279 3.8 0.25 0.43 99 3
1 1 0 985 0 53 0 6.907755279 3.8 0.25 0.43 99 3
0 0 0 987 0 50 0 6.907755279 3.8 0.25 0.43 99 3
3 1 0 981 0 62 1 6.6200732065 3.6 0.16 23 93 3
3 0 0 984 0 43 1 6.6200732065 3.6 0.16 23 93 3
0 3 1 964 1 42 1 5.4380793089 0.6 6.4 1099 63 3
0 3 1 965 1 47 1 5.4380793089 0.6 6.4 1099 63 3
0 3 0 969 0 44 1 5.4380793089 0.6 6.4 1099 63 3
0 3 1 970 1 49 1 5.4380793089 0.6 6.4 1099 63 3
7 3 1 971 1 45 1 5.4380793089 0.6 6.4 1099 63 3
0 3 1 978 1 47 1 5.4380793089 0.6 6.4 1099 63 3
0 1 1 979 1 54 1 5.4380793089 0.6 6.4 1099 63 3
0 3 0 979 0 68 1 5.4380793089 0.6 6.4 1099 63 3
0 1 1 979 1 53 1 5.4380793089 0.6 6.4 1099 63 3
0 1 0 979 0 58 1 5.4380793089 0.6 6.4 1099 63 3
```

```
1 3 1 980 0 50 1 5.4380793089 0.6 6.4 1099 63 3
0 1 1 981 1 48 1 5.4380793089 0.6 6.4 1099 63 3
0 3 0 982 1 45 1 5.4380793089 0.6 6.4 1099 63 3
0 1 0 961 0 44 1 6.6333184333 5 135.6 8512 76 3
2 3 0 961 0 43 1 6.6333184333 5 135.6 8512 76 3
3 1 1 964 1 64 1 6.6333184333 5 135.6 8512 76 3
2 3 0 967 1 65 1 6.6333184333 5 135.6 8512 76 3
4 1 1 969 1 64 1 6.6333184333 5 135.6 8512 76 3
5 1 0 974 1 66 1 6.6333184333 5 135.6 8512 76 3
6 2 0 979 1 60 1 6.6333184333 5 135.6 8512 76 3
2 0 0 985 0 54 1 6.6333184333 5 135.6 8512 76 3
6 1 0 964 0 53 0 6.579251212 -0.1 12.1 757 94 3
2 3 0 970 0 62 0 6.579251212 -0.1 12.1 757 94 3
14 0 1 973 1 58 0 6.579251212 -0.1 12.1 757 94 3
4 1 0 962 1 62 1 6.0867747269 3.2 28.4 1139 88 3
4 1 0 966 0 58 1 6.0867747269 3.2 28.4 1139 88 3
4 1 0 970 0 57 1 6.0867747269 3.2 28.4 1139 88 3
4 1 0 974 0 60 1 6.0867747269 3.2 28.4 1139 88 3
4 1 0 978 0 62 1 6.0867747269 3.2 28.4 1139 88 3
4 0 0 982 0 59 1 6.0867747269 3.2 28.4 1139 88 3
4 1 0 962 0 55 0 6.56526497 2.1 2.6 51 93 3
4 1 0 966 0 50 0 6.56526497 2.1 2.6 51 93 3
4 1 0 974 0 53 0 6.56526497 2.1 2.6 51 93 3
4 1 0 978 0 51 0 6.56526497 2.1 2.6 51 93 3
4 1 0 982 0 56 0 6.56526497 2.1 2.6 51 93 3
1 0 0 986 0 45 0 6.56526497 2.1 2.6 51 93 3
0 1 0 978 0 41 0 6.1527326947 3.9 0.078 1 80 3
0 1 0 979 0 36 0 6.1527326947 3.9 0.078 1 80 3
7 0 0 980 0 61 0 6.1527326947 3.9 0.078 1 80 3
1 3 0 961 0 54 0 6.2538288116 3.9 6.4 49 74 3
1 1 1 962 0 57 0 6.2538288116 3.9 6.4 49 74 3
0 3 0 963 0 54 0 6.2538288116 3.9 6.4 49 74 3
0 3 1 963 0 . 0 6.2538288116 3.9 6.4 49 74 3
2 3 1 963 0 40 0 6.2538288116 3.9 6.4 49 74 3
0 3 1 965 0 . 0 6.2538288116 3.9 6.4 49 74 3
0 3 1 965 1 45 0 6.2538288116 3.9 6.4 49 74 3
0 1 1 965 1 32 0 6.2538288116 3.9 6.4 49 74 3
0 1 0 965 0 44 0 6.2538288116 3.9 6.4 49 74 3
4 2 0 978 0 67 0 6.2538288116 3.9 6.4 49 74 3
4 1 0 982 0 56 0 6.2538288116 3.9 6.4 49 74 3
1 3 1 961 0 42 0 5.9401712527 4.6 9.4 284 85 3
2 3 1 963 1 48 0 5.9401712527 4.6 9.4 284 85 3
0 1 1 966 0 62 0 5.9401712527 4.6 9.4 284 85 3
1 1 0 966 0 45 0 5.9401712527 4.6 9.4 284 85 3
4 3 1 972 1 49 0 5.9401712527 4.6 9.4 284 85 3
2 1 1 976 1 50 0 5.9401712527 4.6 9.4 284 85 3
1 1 0 978 1 . 0 5.9401712527 4.6 9.4 284 85 3
2 2 0 979 0 38 0 5.9401712527 4.6 9.4 284 85 3
3 1 0 981 0 41 0 5.9401712527 4.6 9.4 284 85 3
3 0 0 984 0 53 0 5.9401712527 4.6 9.4 284 85 3
0 3 1 960 1 . 1 5.8579331545 -0.2 4.8 21 65 3
0 3 1 961 1 . 1 5.8579331545 -0.2 4.8 21 65 3
0 1 1 961 1 . 1 5.8579331545 -0.2 4.8 21 65 3
5 1 0 962 1 40 1 5.8579331545 -0.2 4.8 21 65 3
5 1 0 967 1 50 1 5.8579331545 -0.2 4.8 21 65 3
5 1 0 972 1 45 1 5.8579331545 -0.2 4.8 21 65 3
2 3 0 977 1 43 1 5.8579331545 -0.2 4.8 21 65 3
```

```
1 3 1 979 1 43 1 5.8579331545 -0.2 4.8 21 65 3
1 1 1 980 0 55 1 5.8579331545 -0.2 4.8 21 65 3
2 1 0 982 0 56 1 5.8579331545 -0.2 4.8 21 65 3
5 3 0 974 0 52 0 6.0402547113 0.9 0.1 0.34 85 3
4 3 1 979 0 36 0 6.0402547113 0.9 0.1 0.34 85 3
0 3 1 983 1 . 0 6.0402547113 0.9 0.1 0.34 85 3
1 1 1 983 0 44 0 6.0402547113 0.9 0.1 0.34 85 3
3 0 0 984 0 66 0 6.0402547113 0.9 0.1 0.34 85 3
3 1 1 963 1 55 1 6.2146080984 2.1 8 109 50 3
4 1 0 966 1 51 1 6.2146080984 2.1 8 109 50 3
4 1 0 970 1 52 1 6.2146080984 2.1 8 109 50 3
4 1 0 974 1 44 1 6.2146080984 2.1 8 109 50 3
4 1 0 978 0 54 1 6.2146080984 2.1 8 109 50 3
0 3 0 982 1 56 1 6.2146080984 2.1 8 109 50 3
1 3 1 982 1 56 1 6.2146080984 2.1 8 109 50 3
3 1 1 983 1 53 1 6.2146080984 2.1 8 109 50 3
1 0 0 986 0 44 1 6.2146080984 2.1 8 109 50 3
18 2 0 966 0 43 1 6.0161571597 0.5 0.79 215 85 3
2 0 0 985 0 56 1 6.0161571597 0.5 0.79 215 85 3
15 3 0 971 0 20 1 5.2983173665 1.1 5.9 28 23 3
1 0 1 985 1 54 1 5.2983173665 1.1 5.9 28 23 3
11 3 1 963 1 42 1 5.7683209958 0.6 4.4 112 56 3
3 3 1 975 1 44 1 5.7683209958 0.6 4.4 112 56 3
3 1 1 978 1 . 1 5.7683209958 0.6 4.4 112 56 3
4 1 0 982 0 48 1 5.7683209958 0.6 4.4 112 56 3
1 0 0 986 0 59 1 5.7683209958 0.6 4.4 112 56 3
5 1 0 962 0 78 0 6.8977049431 -0.5 2.2 11 74 3
0 2 0 967 0 55 0 6.8977049431 -0.5 2.2 11 74 3
5 1 0 967 0 44 0 6.8977049431 -0.5 2.2 11 74 3
8 1 0 972 0 48 0 6.8977049431 -0.5 2.2 11 74 3
7 0 0 980 0 50 0 6.8977049431 -0.5 2.2 11 74 3
6 1 0 964 0 53 0 6.7912214627 3.2 78.8 1973 88 3
6 1 0 970 0 48 0 6.7912214627 3.2 78.8 1973 88 3
6 1 0 976 0 52 0 6.7912214627 3.2 78.8 1973 88 3
5 0 0 982 0 48 0 6.7912214627 3.2 78.8 1973 88 3
3 2 1 963 0 53 0 6.2915691396 -1.8 3.3 130 88 3
0 3 0 966 0 66 0 6.2915691396 -1.8 3.3 130 88 3
11 3 1 967 1 34 0 6.2915691396 -1.8 3.3 130 88 3
6 0 1 981 0 36 1 6.2915691396 -1.8 3.3 130 88 3
4 3 0 964 0 59 0 6.82437367 2.9 2.2 77 90 3
0 1 1 968 0 . 0 6.82437367 2.9 2.2 77 90 3
0 1 0 968 0 63 0 6.82437367 2.9 2.2 77 90 3
12 2 1 968 1 39 0 6.82437367 2.9 2.2 77 90 3
0 3 1 981 1 . 0 6.82437367 2.9 2.2 77 90 3
0 3 1 982 1 48 0 6.82437367 2.9 2.2 77 90 3
5 0 1 982 1 . 0 6.82437367 2.9 2.2 77 90 3
0 3 0 962 0 67 1 6.429719478 0.1 18.6 1285 80 3
0 3 1 962 1 59 1 6.429719478 0.1 18.6 1285 80 3
0 1 1 963 1 . 1 6.429719478 0.1 18.6 1285 80 3
5 3 0 963 0 50 1 6.429719478 0.1 18.6 1285 80 3
6 3 1 968 1 58 1 6.429719478 0.1 18.6 1285 80 3
4 1 1 975 1 54 1 6.429719478 0.1 18.6 1285 80 3
2 0 0 985 0 36 1 6.429719478 0.1 18.6 1285 80 3
4 0 0 983 0 47 0 6.551080335 3.1 0.043 0.26 80 3
0 1 0 979 0 53 0 6.3456363608 3.1 0.136 0.62 78 3
2 1 0 979 0 62 0 6.3456363608 3.1 0.136 0.62 78 3
0 1 0 981 0 55 0 6.3456363608 3.1 0.136 0.62 78 3
```

```
0 1 0 982 0 36 0 6.3456363608 3.1 0.136 0.62 78 3
5 1 0 979 0 64 0 5.8579331545 1.8 0.119 0.39 82 3
3 0 0 984 0 53 0 5.8579331545 1.8 0.119 0.39 82 3
6 3 0 973 0 37 1 7.2225660188 4.5 0.393 163 65 3
1 1 1 980 0 43 1 7.2225660188 4.5 0.393 163 65 3
6 0 0 981 1 . 1 7.2225660188 4.5 0.393 163 65 3
19 2 0 962 0 50 1 6.8772960715 3.4 1.2 5 98 3
5 1 1 981 0 49 1 6.8772960715 3.4 1.2 5 98 3
1 0 0 986 0 60 1 6.8772960715 3.4 1.2 5 98 3
1 1 0 960 0 . 0 6.8564619846 2 3 176 94 3
1 1 0 961 0 . 0 6.8564619846 2 3 176 94 3
1 1 0 962 0 . 0 6.8564619846 2 3 176 94 3
1 1 0 963 0 . 0 6.8564619846 2 3 176 94 3
0 2 0 964 0 70 0 6.8564619846 2 3 176 94 3
0 1 0 965 0 50 0 6.8564619846 2 3 176 94 3
1 1 0 965 0 . 0 6.8564619846 2 3 176 94 3
0 1 0 966 0 50 0 6.8564619846 2 3 176 94 3
0 1 0 966 0 . 0 6.8564619846 2 3 176 94 3
0 1 0 967 1 66 0 6.8564619846 2 3 176 94 3
4 1 0 967 0 47 0 6.8564619846 2 3 176 94 3
5 3 0 971 0 43 0 6.8564619846 2 3 176 94 3
0 3 1 976 0 80 0 6.8564619846 2 3 176 94 3
5 3 1 976 0 72 0 6.8564619846 2 3 176 94 3
3 1 1 981 1 56 0 6.8564619846 2 3 176 94 3
2 0 0 985 0 49 0 6.8564619846 2 3 176 94 3
5 1 0 964 0 58 0 7.3963352938 1.5 17.3 912 86 3
5 1 0 969 0 53 0 7.3963352938 1.5 17.3 912 86 3
5 1 0 974 0 52 0 7.3963352938 1.5 17.3 912 86 3
5 1 0 979 0 53 0 7.3963352938 1.5 17.3 912 86 3
4 0 0 984 0 59 0 7.3963352938 1.5 17.3 912 86 3
;

/* Raw cox model analysis for subsetting dataset */
PROC PHREG DATA=leaders;
class region;
   MODEL years*lost(0)=age region manner loginc literacy;
 Run;

/* Subset and simplify dataset */
DATA leaders1;
   SET leaders;
   KEEP years lost manner age loginc literacy region;
RUN;

/* Delete Region 0, 1, and 4 (actually, no data on region 4) and only analyze
data in two regions (Asia and Latin America) "    */
DATA leaders2;
  SET leaders1;
  IF region =0 THEN DELETE ;
  IF region =3 THEN DELETE ;
RUN;

/* Export subsetted data for R analysis "    */
proc export data=leaders2
   outfile='D:\R\leaders2.csv'
   dbms=csv
   replace;
```

```
run;

/* Introduce new variable "event" in the dataset based on specific causes of
exit
   and treat completing risk events as censored*/
DATA const;
  SET leaders2;
  event=(lost=1);
  type=1;
 Run;

DATA nat;
  SET leaders2;
  event=(lost=2);
  type=2;
 Run;

 DATA noncon;
  SET leaders2;
  event=(lost=3);
  type=3;
 Run;
/* Combined reshaped dataset*/
DATA combine;
  SET const nat noncon;
 Run;

/* Export "combine" for R analysis    */
proc export data=combine
   outfile='D:\R\combine.csv'
   dbms=csv
   replace;
run;
Proc Format;
value Type 1='C-exit: constitutional' 2='N-exit: dealth' 3="N-exit:
nonconstitutional";
run;

PROC LIFETEST DATA=COMBINE PLOTS=LLS;
  TIME years*event(0);
  STRATA type;
  Format type type.;
RUN;
/* Death-specific commulative incidence by macro analysis*/
ODS GRAPHICS ON;
PROC LIFETEST DATA=combine PLOTS=H(BW=10);
  TIME years*event(0);
  STRATA type;
  Format type type.;
  RUN;
ODS GRAPHICS OFF;

/* Cox model: all types combined analysis including region*/
PROC PHREG DATA=leaders2;
   MODEL years*lost(0)=age region manner loginc;
 Run;
```

```
/* Cox model: all types combined analysis without region due to insignificant
difference in the above model*/
PROC PHREG DATA=leaders2;
   MODEL years*lost(0)=age manner loginc;
 Run;
/* Cox model: contitutional-specific hazard analysis*/

PROC PHREG DATA=leaders2;
   MODEL years*lost(0,2,3)=age manner loginc;
 Run;

 /* Cox model: death-specific hazard analysis*/
PROC PHREG DATA=leaders2;
   MODEL years*lost(0,1,3)=age manner loginc;
Run;

/* Cox model: noncontitutional-specific hazard analysis*/
PROC PHREG DATA=leaders2;
   MODEL years*lost(0,1,2)=age manner loginc;
 run;

 /* Cox model: contitutinal/noncontitutional-specific hazard analysis*/
PROC PHREG DATA=leaders2;
   MODEL years*lost(0,2)=age loginc;
   STRATA region;
 Run;

 /*Contitutional-specific commulative incidence by macor analysis*/
%CUMINCID(DATA=leaders2,
           TIME=years,
           STATUS=lost,
           EVENT=1,
           COMPETE=1 2,
           CENSORED=0)
run;

/* Death-specific commulative incidence by macro analysis*/
%CUMINCID(DATA=leaders2,
           TIME=years,
           STATUS=lost,
           EVENT=2,
           COMPETE=1 2,
           CENSORED=0);
run;

/* Acquire cumhaz of c-exit*/
PROC PHREG DATA=leaders2 PLOTS=CUMHAZ;
   MODEL years*lost(0,2,3)=age manner loginc;
   baseline out = exit1 cumhaz=cexitcumhaz;
 Run;
/* Export "exit1 cumulative hazard" for R analysis    */
proc export data=exit1
   outfile='D:\R\exit1.csv'
   dbms=csv
   replace;
run;
```

```
/* Acquire cumhaz of D-exit*/
PROC PHREG DATA=leaders2 PLOTS=CUMHAZ;
   MODEL years*lost(0,1,3)=age manner loginc;
   baseline out = exit2 cumhaz=dexitcumhaz;
 run;
/* Export "exit2 cumulative hazard" for R analysis    */
proc export data=exit2
   outfile='D:\R\exit2.csv'
   dbms=csv
   replace;
run;

/* Acquire cumhaz of c-exit*/
PROC PHREG DATA=leaders2 PLOTS=CUMHAZ;
   MODEL years*lost(0,1,2)=age manner loginc;
   baseline out = exit3 cumhaz=nexitcumhaz;
 Run;
/* Export "exit3 cumulative hazard" for R analysis    */
proc export data=exit3
   outfile='D:\R\exit3.csv'
   dbms=csv
   replace;
run;

/* Export KM estimate for plotting in R */
PROC LIFETEST DATA=COMBINE outsurv=estimate;
  TIME years*event(0);
  STRATA type;
  Format type type.;
RUN;

/* Export KM estimate for plotting in R */
Data kmestimate;
  set estimate;
    cumhaz = -log(survival);
  run;
proc export data=kmestimate
   outfile='D:\R\kmestimate.csv'
   dbms=csv
   replace;
run;

/* Nonconstitutional-specific commulative incidence by macro analysis*/
%CUMINCID(DATA=leaders2,
           TIME=years,
           STATUS=lost,
           EVENT=2,
           COMPETE=1 2,
           CENSORED=0);
run;
```

Appendix II: R codes

```
#-------------------------------------------------
# project: Compete Risks
# original: 4/30/2014
# Name: Yonghua Zhuang
# for: 6646 Survival Analysis Spring 2014
# -------------------------------------------------
# Load the package (needed whenever using the package)
library(KMsurv)
library(km.ci)
library(survival)   # Standard survival package in R
library(gridExtra)
library(cmprsk)     # Competeting risk analysis package in R
library(ggplot2)
library(reshape)

# Import Data set
combine <- read.csv("combine.csv", header=T)
head(combine)

# Estimate overall K-M curve without covariates and stratitication
km.fit0 <- survfit(Surv(years, event)~1,data=combine,
                   type = c("kaplan-meier"))

# Descriptive stats and list of output variables
summary(km.fit0)
km.fit0
attributes(km.fit0)

# overall K-M survival kurve
plot(km.fit0, conf.int=F, xlab="time until exit (in years)",
     ylab="proportion in power",
     cex=2, lty=1, col=4)
mtext("K-M Survival Curve for leader's power ")

# Estimate cause-specific K-M curve:
km.fit <- survfit(Surv(years, event)~strata(type),data=combine,
                   type = c("kaplan-meier"))

# Descriptive stats and list of output variables
summary(km.fit)
km.fit
attributes(km.fit)

# K-M survival plot for each categories of exit (casuse-specific)
plot(km.fit, xlab="time until exit (in years)",
     ylab="proportion in power",
     lab=c(10,10,7), cex=2, lty=1:3, col=1:3)
legend(2,.35, c("C-exit: constitutional", "D-exit: death", "N-exit:
nonconstitutional"), lty=1:3, col=1:3)
mtext("K-M Survival Curve for leader's power")

# log K-M survival plot (cumulative hazard)
plot(km.fit,conf.int=F, xlab="time until exit (in years)",
     ylab="cumulative hazard", fun="cumhaz",
     lab=c(10,10,7), cex=2, lty=1:3, col=1:3)
```

```
legend(0.2,1.2, c("C-exit: constitutional", "D-exit: death", "N-exit:
nonconstitutional"),lty=1:3, col=1:3)
mtext("K-M Cumulative Hazard Curve for leader's power")

# Import cause-specific cumulative hazard estimation
exit1 <- read.csv("exit1.csv", header=T)
exit2 <- read.csv("exit2.csv", header=T)
exit3 <- read.csv("exit3.csv", header=T)

# Plot 3 individual cause-specific cululative hazard estimation and dispaly
the poetential problem in cause-specific analysis
g1<-ggplot(exit1, aes(x = years, y = cexitcumhaz, colour="black")) +
geom_line()
g2<-ggplot(exit2, aes(x = years, y = dexitcumhaz, colour = "green")) +
geom_line()
g3<-ggplot(exit3, aes(x = years, y = nexitcumhaz, colour ="red")) +
geom_line()
grid.arrange(g1+theme(legend.position="none"),
g2+theme(legend.position="none"), g3+theme(legend.position="none"),ncol=3)


# Import data for cumulative incidence analysis
leader <- read.csv("leaders2.csv", header=T)

attach (leader)

los=factor(lost, levels=c(0:3), labels= c("In-power", "C-exit", "D-exit", "N-
exit"))

mann=factor(manner, levels=c(0,1), labels= c("M0: Consti-power", "M1: Noncon-
power "))

# Summary data with tables
table(mann, los)
tapply(years, list(mann, los), mean)

## cuminc(ftime, fstatus, group, cencode=0,...) where
## ftime is failure time, fstatus is failure status, group is optional group
indicator
## cencode is the code for censored observations in fstatus
fit.1 <- cuminc(leader$years, leader$lost, cencode=0)
fit.1

## plot competing risks
plot(fit.1)

## to customize, use custom function from package
plot(fit.1, col=1:3, curvlab=c("C-exit: constional", "D-exit: death", "N-exit:
nonconstional"),xlab="Years Post power",ylim=c
     (0,1), ylab="Probability", main="Competing Risks:
\aCumulative Incidence of exits")

## using timepoints(w, times)
## w is a cuminc() object, times is vector of time
fits.1c <- timepoints(fit.1,leader$years)
fits.1c
```

```
## convert list to df, format nicely
df <- as.data.frame(cbind(t(fits.c$est),t(fits.c$var)))
names(df) <- c("Cexit", "Dexit", "Nexit", "var(Cexit)",
"var(Dexit)","var(Nexit)")
row.names(df) <- c(1:length(df[[1]]))

## Add times to the dataframe
df$time <- sort(unique(leader$years))
head(df)
## rearrange order of display and subset
dfCI <- df[,c(7,1:3)]
head(dfCI)
tail(dfCI)

## Stacking C,D, E cumulative incidence
dfCI$CDexit<-dfCI$Cexit + dfCI$Dexit
dfCI$CDNexit<-dfCI$Cexit + dfCI$Dexit+ dfCI$Nexit
head(dfCI)
## Export cumulative incidence estimates
write.table(dfCI, "dfCI.xls", quote=FALSE, sep="\t")

## Reorganize dataframe for plotting
stackedCI <- dfCI[,c(1,2,5, 6)]
head(stackedCI)

# Plot Stacked cumulative incidence
Molten1 <- melt(stackedCI, id.vars = "time")
head(Molten1)

g1<- ggplot(Molten1, aes(x =time, y = value, colour = variable,
ylab="cumulative incidence")) + geom_line()
g1

# Alternative codes for cumulative incidence estimation and ploting
source ("CumIncidence.R")
# Cumulative incidence estimation with Gray's test for group comparison
fit=CumIncidence (years, lost, cencode = 0, xlab="Years")

## cuminc(ftime, fstatus, group, cencode=0,...) where
## ftime is failure time, fstatus is failure status, group is optional group
indicator
## cencode is the code for censored observations in fstatus

fit.2 <- cuminc(leader$years, leader$lost, leader$manner, cencode=0)
fit.2

## using timepoints(w, times)
## w is a cuminc() object, times is vector of time
fits.c2 <- timepoints(fit.1,leader$years)
fits.c2

## plot competing risks
plot(fit.2)
dev.off()
## to customize, use custom function from package
plot(fit.2, col=c(1,1,2,2,3,3), curvlab=c("M0 C-exit", "M1 C-exit", "M0 D-
exit", "M1 D-exit", "M0 N-exit", "M1 N-exit"), xlab="Years Post power",ylim=c
```

```
     (0,1), ylab="Cumulative Incidence", main="Competing Risks:
\aCumulative Incidence of exits")

# Alternative codes for gray's test+ploting with "CumIncidence" function
# source function of "CumIncidence"
source ("CumIncidence.R")
# Cumulative incidence estimation with Gray's test for group comparison
fit=CumIncidence (years, lost, manner, cencode = 0, xlab="Years")
```

Appendix III: CumIncidence function in R

```
#############################################################################
#                                                                           #
#                  CUMULATIVE INCIDENCE CURVES IN R                         #
#                                                                           #
# Written by Luca Scrucca                                                   #
#                                                                           #
# Reference:                                                                #
# Scrucca L., Santucci A., Aversa F. (2007) Competing risks analysis using  #
#   R: an easy guide for clinicians. Bone Marrow Transplantation, 40,       #
#   381--387.                                                               #
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# ver. 1.1 Feb 2008
#          - allow group to be missing
#          - if t is provided both computation and plots use t as time points
#          - allow col, lwd to be used for curves with confidence bands
#          - fix some bugs in the legend
#          - added help on source code
# ver. 1.0 May 2007
#          - Version appearing in the BMT paper
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#
# Usage:
#
#   CumIncidence(ftime, fstatus, group, t, strata, rho = 0, cencode = 0,
#                subset, na.action = na.omit, level,
#                xlab = "Time", ylab = "Probability",
#                col, lty, lwd, digits = 4)
#
# Arguments:
#
# ftime = failure time variable.
# fstatus = variable with distinct codes for different causes of
#           failure and also a distinct code for censored observations.
# group = estimates will be calculated within groups given by distinct
#         values of this variable. Tests will compare these groups. If
#         missing then treated as all one group (no test statistics).
# t = a vector of time points where the cumulative incidence function
#     should be evaluated.
# strata = stratification variable. Has no effect on estimates. Tests
#          will be stratified on this variable. (all data in 1 stratum,
#          if missing).
# rho = power of the weight function used in the tests. By default is
#       set to 0.
# cencode = value of fstatus variable which indicates the failure time
#           is censored.
# subset = a logical vector specifying a subset of cases to include in
#          the analysis.
# na.action = a function specifying the action to take for any cases
#             missing any of ftime, fstatus, group, strata, or subset.
#             By default missing cases are omitted.
# level = a value in the range [0,1] specifying the level for pointwise
#         confidence bands.
# xlab = text for the x-axis label.
# ylab = text for the y-axis label.
# col = color(s) used for plotting curves (see plot.default).
```

```
# lty = line type(s) used for plotting curves (see plot.default).
# lwd = line width(s) used for plotting curves (see plot.default).
# digits = number of significant digits used for printing values. By
#          default set at 4.
#
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"CumIncidence" <- function(ftime, fstatus, group, t, strata, rho = 0,
                           cencode = 0, subset, na.action = na.omit, level,
                           xlab = "Time", ylab = "Probability",
                           col, lty, lwd, digits = 4)
{
  # check for the required package
  if(!require("cmprsk"))
    { stop("Package `cmprsk' is required and must be installed.\n
           See help(install.packages) or write the following command at
prompt
           and then follow the instructions:\n
           > install.packages(\"cmprsk\")") }
  # collect data
  mf  <- match.call(expand.dots = FALSE)
  mf[[1]] <- as.name("list")
  mf$t <- mf$digits <- mf$col <- mf$lty <- mf$lwd <- mf$level <-
  mf$xlab <- mf$ylab <- NULL
  mf <- eval(mf, parent.frame())
  g <- max(1, length(unique(mf$group)))
  s <- length(unique(mf$fstatus))
  if(missing(t))
    { time <- pretty(c(0, max(mf$ftime)), 6)
      ttime <- time <- time[time < max(mf$ftime)] }
  else { ttime <- time <- t }
  # fit model and estimates at time points
  fit   <- do.call("cuminc", mf)
  tfit <- timepoints(fit, time)
  # print result
  cat("\n+", paste(rep("-", 67), collapse=""), "+", sep ="")
  cat("\n| Cumulative incidence function estimates from competing risks data
|")
  cat("\n+", paste(rep("-", 67), collapse=""), "+\n", sep ="")
  tests <- NULL
  if(g > 1)
    { tests <- fit$Tests
        colnames(tests) <- c("Statistic", "p-value", "df")
      cat("Test equality across groups:\n")
      print(tests, digits = digits) }
  cat("\nEstimates at time points:\n")
  print(tfit$est, digits = digits)
  cat("\nStandard errors:\n")
  print(sqrt(tfit$var), digits = digits)
  #
  if(missing(level))
    { # plot cumulative incidence functions
      if(missing(t))
        { time <- sort(unique(c(ftime, time)))
          x <- timepoints(fit, time) }
      else x <- tfit
      col <- if(missing(col)) rep(1:(s-1), rep(g,(s-1))) else col
```

```
      lty <- if(missing(lty)) rep(1:g, s-1) else lty
      lwd <- if(missing(lwd)) rep(1, g*(s-1)) else lwd
      matplot(time, base::t(x$est), type="s", ylim = c(0,1),
              xlab = xlab, ylab = ylab, xaxs="i", yaxs="i",
              col = col, lty = lty, lwd = lwd)
      legend("topleft", legend =  rownames(x$est), x.intersp = 2,
             bty = "n", xjust = 1, col = col, lty = lty, lwd = lwd)
      out <- list(test = tests, est = tfit$est, se = sqrt(tfit$var))
    }
  else
    { if(level < 0 | level > 1)
        error("level must be a value in the range [0,1]")
      # compute pointwise confidence intervals
      oldpar <- par(ask=TRUE)
      on.exit(par(oldpar))
      if(missing(t))
        { time <- sort(unique(c(ftime, time)))
          x <- timepoints(fit, time) }
      else x <- tfit
      z <- qnorm(1-(1-level)/2)
      lower <- x$est ^ exp(-z*sqrt(x$var)/(x$est*log(x$est)))
      upper <- x$est ^ exp(z*sqrt(x$var)/(x$est*log(x$est)))
      col <- if(missing(col)) rep(1:(s-1), rep(g,(s-1)))
             else             rep(col, g*(s-1))
      lwd <- if(missing(lwd)) rep(1, g*(s-1))
             else             rep(lwd, g*(s-1))
      # plot pointwise confidence intervals
      for(j in 1:nrow(x$est))
         { matplot(time, cbind(x$est[j,], lower[j,], upper[j,]), type="s",
                   xlab = xlab, ylab = ylab, xaxs="i", yaxs="i",
                   ylim = c(0,1), col = col[j], lwd = lwd[j], lty = c(1,3,3))
           legend("topleft", legend =  rownames(x$est)[j], bty = "n", xjust =
1) }
      # print pointwise confidence intervals
      i <- match(ttime, time)
      ci <- array(NA, c(2, length(i), nrow(lower)))
      ci[1,,] <- base::t(lower[,i])
      ci[2,,] <- base::t(upper[,i])
      dimnames(ci) <- list(c("lower", "upper"), ttime, rownames(lower))
      cat(paste("\n", level*100, "% pointwise confidence intervals:\n\n",
sep=""))
      print(ci, digits = digits)
      out <- list(test = tests, est = x$est, se = sqrt(tfit$var), ci = ci)
    }
  # return results
  invisible(out)
}
```