Motivation for Using Network Analysis

- Min-cost network solution solves the problem of matching units to tasks in order to implement a logistics or obstacle emplacement plan
- Evaluates the effect of removing road segments or movement corridors from the overall routing
  - Requires the determination first of a road network or unit movement mobility corridors on the digital map
  - Maximun flow network solution for off-road movement corridors allows determination of effect of delay by measuring throughput with and without obstacles
  - Using only individual mobility corridors it is harder to tell how these factors are affected by cross-corridor movement possiblities

Network Analysis Motivation (cont.)

- When an obstacle plan is being analyzed and weapon sites are added, the min-cost network solution allows the determination of the overall effect on moving units being exposed to enemy fire
- For a logistics plan the importance of bomb damage repair to the accomplishment of the overall haul capacity can be evaluated

Network Algorithms for Obstacle Planning and Task Scheduling

- **1988 Programs written in PROLOG to do network maximal flow vehicle throughput and minimal cost routing**
  - Algorithms based on a depth-first search version of a procedure developed by Edmonds/Karp
- **1989 Programs put into an early interactive Turbo Pascal version of CAMMS**
  - Demonstrated for US V Corps area in Germany using mobility speed prediction and terrain data
  - Corps level tactical movement plans analysed, results published in WES report GL-89-4
  - Input from the Engineer School for obstacle breaching times and for a list of standard obstacles

- **1990 Algorithms rewritten and put into an improved C-language version of CAMMS**
  - National Training Center terrain areas digitized, members of Fort Riley Kansas engineer staff trained in use
  - Programs put in a HMMV and taken to a mechanized division rotation cycle at the NTC
  - ARO paper written which determines computational complexity of these versions of the max-flow, min-cost algorithms
- **1991 - l994 Present version of Obstacle Planning System (OPS) written to go inside of the engineer module of ATCCS**
  - Did not have network analysis capability
  - Had automated mobility corridor generation which used a unit movement raster grid version of the A* algorithm

- **1995 3rd C-language version of the network algorithm written which has better memory allocation and other features**
  - C code written to determine, using a max-min metric, point streams of coordinates of differences between mobility corridors
  - Algorithms written to take unit weapon scores from Fort Leavenworth and interpolate values across a spatial area. These values then used to provide an alternate way to generate mobility corridors which takes account of weapon siting (through LOS count) and unit firepower.
  - Preprocessor written to filter out no-go cells from raster data, then automatically generate a grid movement network for routing and throughput analysis. Breath-first path search version of the max-flow algorithm to improve the speed of the throughput algorithm
  - C-language code written to use the min-cost version of the network algorithms to do unit/task scheduling (transportation problem)

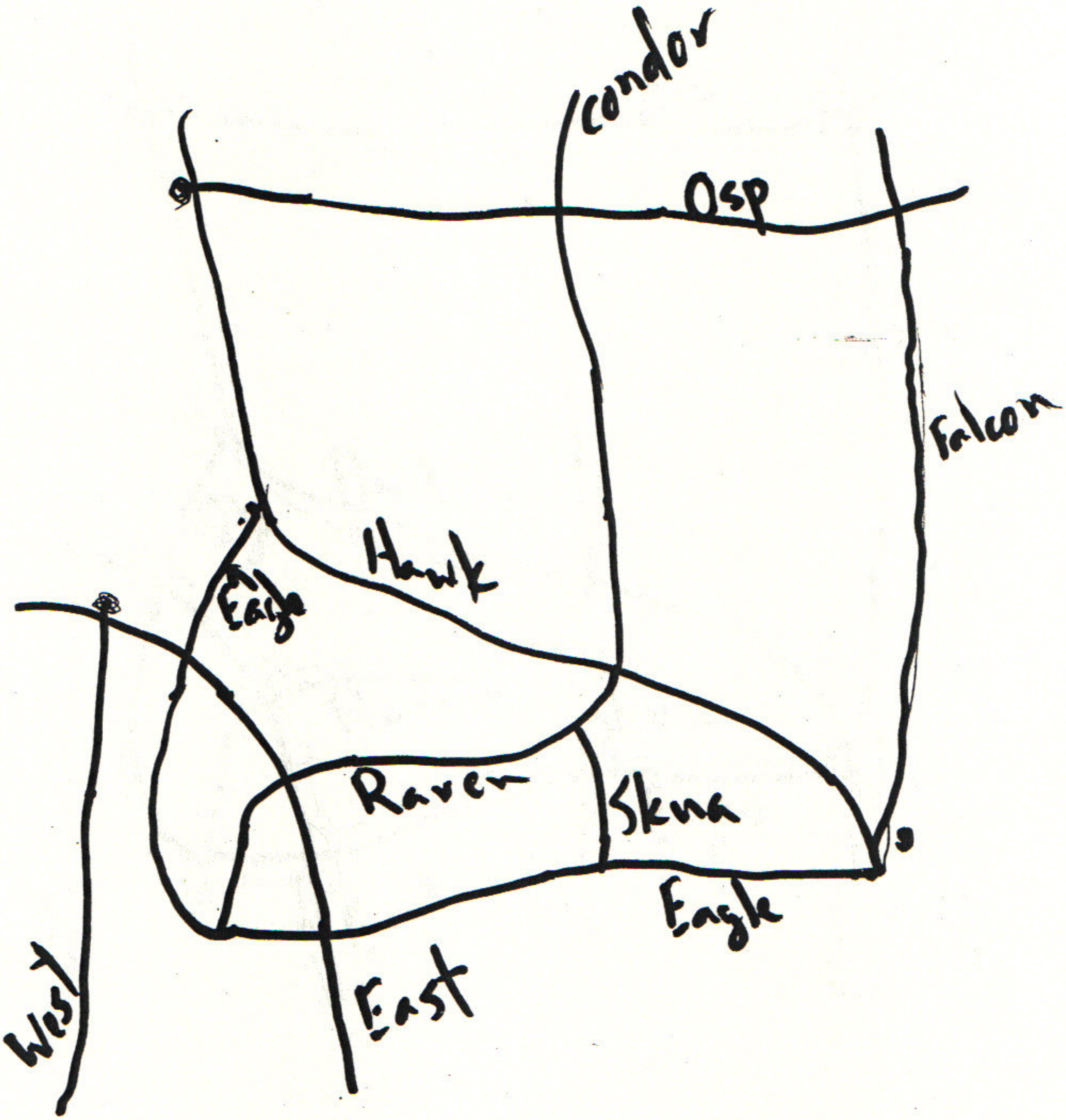
Examples of Network Flow Path Routing and Scheduling

- **Off road movement corridors, Germany 1988**
  - Throughput values can be used to measure obstacle effectiveness. It affects capability of the defense to deal with attacking vehicles.
- **On road logistics movement, Korea 1996**
  - Throughput values determine time-critical haul capacity for largest US Army obstacle emplacement plan.

- Network examples for both scenarios solved by a multiple start point , multiple end point, path searching, goal seeking, backtracking algorithm.
- Algorithm extends partial paths by sorting non-cyclic routes at each new search stage.
- It solves both the max-flow and minimal cost throughput problem.
- Networks allow bidirectional edges.
- Unit / task resource scheduling problem can be solved by adding work time to network nodes.

- Code for main algorithm written in C
- Method differs from other depth-first search procedures in that it saves information about partial solution paths. This allows the same computer procedures to be used to solve both the max-flow and min-cost problem.
- Code for a separate algorithm written to compute throughput of large network using breath first search and the method of preflows.
- Both programs use far pointers, sparse matrix data structures, indirection of list data structures. This allows portability for use in problems with different network edge data type structures.

Korea


condor
Osp
Falcon
Hawk
Eagle
Raven
Skna
Eagle
West
East

Class V Storage Sites

5230	CP890770	ASP1
5251	CP890570	ASP2
5251	CP010925	ASP3
5253	CP030430	ASP4
5254	CP033440	ASP5

Port Storage Sites

5235	CP900455	PSS 1

MS Route Capacity (1000 Short Tons/Day)

Route	Length (km)	5Ton	10Ton	18Ton	Speed (k.p.h)	Time to Travers (minutes)
Skua	63	92.1	165.8	257.9	50	75.6
Condor	198	76.7	138.1	214.8	50	237.6
Osprey	178	92.1	165.8	257.9	50	213.6
Raven	178	92.1	165.8	257.9	50	213.6
East	195	46	82.9	129.3	50	234
West	152	46	92.9	129.3	50	182.4
Eagle	402	46	82.9	129.3	50	482.4
Hawk	410	92.1	165.8	257.9	50	492
Falcon	450	46	82.9	129.3	50	540

route segment traverse times

start nd	end nd	length (km.)	speed (km./hr.)	time to traverse
19	4	15	50	18
1	4	152	50	182.4
4	5	20	50	24
3	5	112	50	134.4
5	3	112	50	134.4
3	6	29	50	34.8
3	7	40	50	48
7	3	40	50	48
2	7	55	50	66
7	8	112	50	134.4
8	12	80	50	96
6	7	51	50	61.2
7	6	51	50	61.2
5	6	53	50	63.6
6	5	53	50	63.6
6	9	114	50	136.8
8	9	63	50	75.6
5	10	56	50	67.2
9	11	35	50	42

10	11	112	50	134.4

11	10	112	50	134.4
11	12	108	50	129.6
12	11	108	50	129.6
10	15	110	50	132
11	14	128	50	153.6
12	23	265	30	530
15	16	80	50	96
14	17	70	50	84
13	18	91	50	109.2
20	8	60	50	72
21	12	60	50	72
23	13	100	30	200
15	14	73	30	146
14	15	73	30	146
14	13	75	30	150
13	14	75	30	150
22	23	5	30	10

10 Ton Trucks

Sources	Total Throughput	Best Routings
	1000 short tons	[nodes] flow (1000 ST) traverse time (min.)
2 22	166	[22 23 13 18] 83 320 [2 7 6 9 11 14 17] 83 483
[2 20 22]	249	[22 23 13 18] 83 320 [20 8 9 11 14 17] 83 428 [2 7 6 9 11 14 17] 55 483 [2 7 6 5 10 15 16] 28 486
1 2 22 20 21	387	[22 23 13 18] 83 320 [20 8 9 11 14 17] 83 428 [21 12 11 14 17] 55 440 [2 7 6 5 10 15 16] 83 486 [21 12 11 10 15 16] 28 564 [1 4 5 6 9 11 10 15 16] 55 750

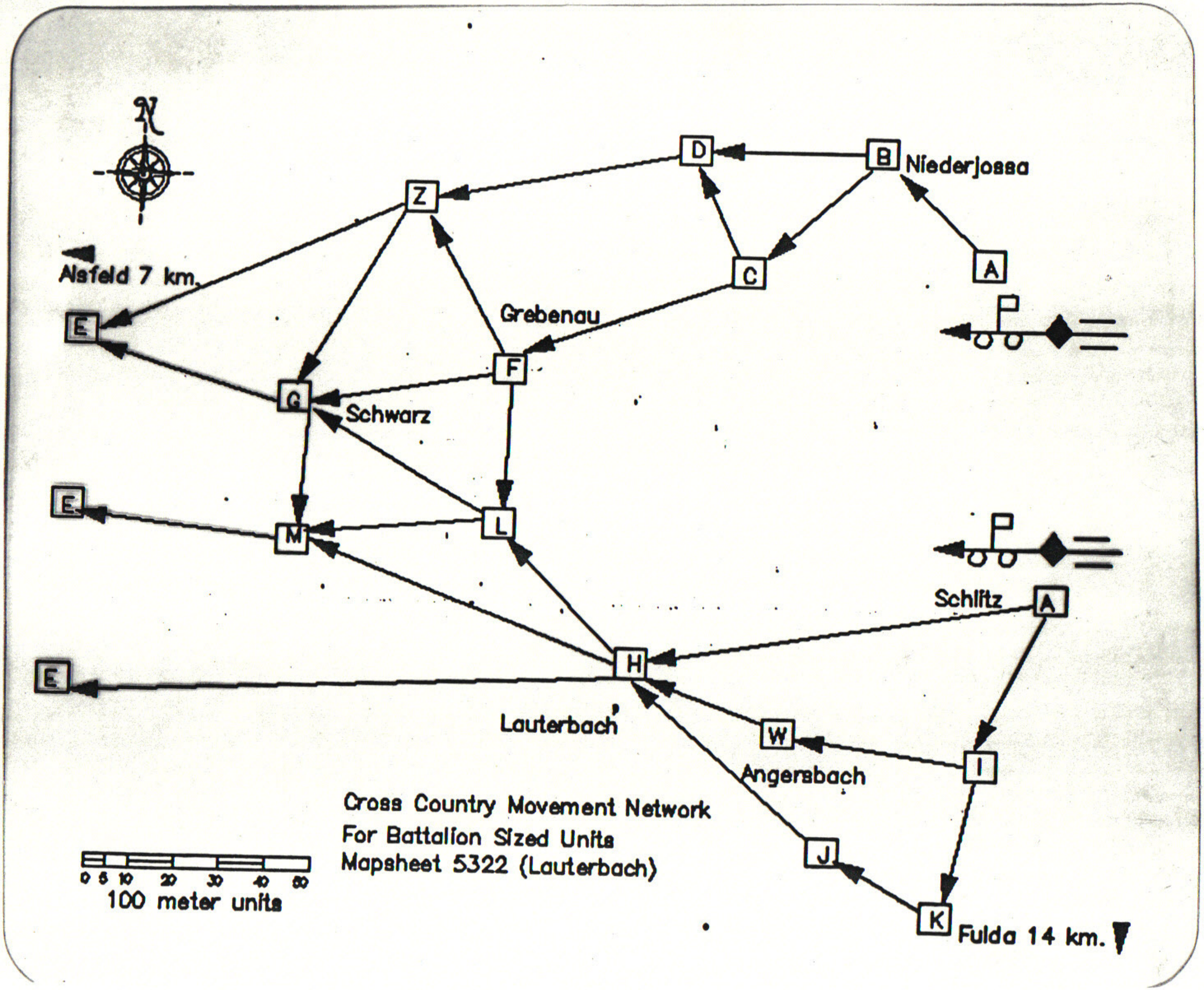
Results
Throughput Analysis

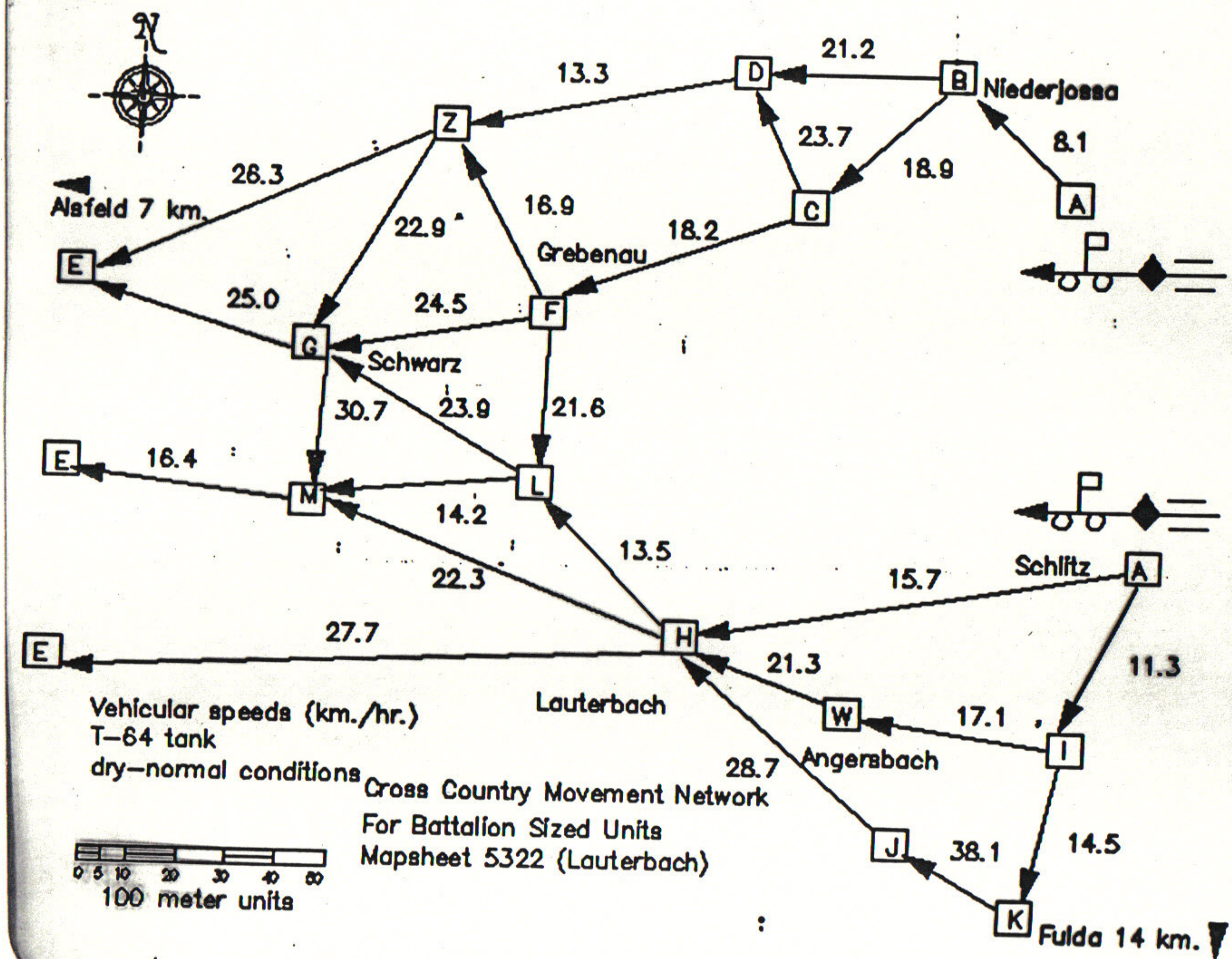
3 Nodes 16,17,18 are sinks

5 Ton Trucks

Sources	Total Throughput 1000 short tons	Best Routings [nodes] flow (1000 ST) traverse time (min.)
2 21	92	[21 12 11 14 17] 46 440
		[2 7 6 9 11 14 17] 46 483
2 20 21	138	[20 8 9 11 14 17] 46 428
		[21 12 11 14 17] 46 440
		[2 7 6 5 10 15 16] 46 486
1 2 22 20 21	184	[22 23 13 18] 46 320
		[20 8 9 11 14 17] 46 428
		[21 12 11 14 17] 46 440
		[2 7 6 5 10 15 16] 46 486

Germany


Alsfeld 7 km.
Niederjossa
Grebenau
Schwarz
Schlitz
Lauterbach
Angersbach
Fulda 14 km.
A
B
C
D
Z
F
G
L
M
H
W
I
J
K
E
E
E
0 5 10 20 30 40 50
100 meter units
Cross Country Movement Network
For Battalion Sized Units
Mapsheet 5322 (Lauterbach)



Vehicular speeds (km./hr.)
T–64 tank
dry–normal conditions

Cross Country Movement Network
For Battalion Sized Units
Mapsheet 5322 (Lauterbach)

SHORTEST PATHS 5322AA.PHS ,PRED FILE: WESTP.PRD

T-64 DRY, NORMAL

AHE time(min)= 48.7

AIWHE time(min)= 56.8

AHME time(min)= 63.0

AIKJHE time(min)= 66.2

ABDZE time(min)= 67.2

ABCFGE time(min)= 67.2

AIWHME time(min)= 71.0

ABCFGME time(min)= 74.1

ABCDZE time(min)= 74.9

ABCFLGE time(min)= 76.2

ABCFLME time(min)= 78.9

AHLGE time(min)= 79.8

AIKJHME time(min)= 80.5

ABDZGE time(min)= 80.6

ABCFZE time(min)= 81.4

AHLME time(min)= 82.5

ABCFLGME time(min)= 83.0

AHLGME time(min)= 86.7

ABDZGME time(min)= 87.4