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Economic Approach of Tinplate Production by Correlating Customers Demand and Production Parameters through Numerical Simulation

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Abstract

Competition to tinplate industry leads to continuous thrust on down gauging, improvement in mechanical properties, lesser coating without sacrificing preservative properties .This paper studies effect of temper rolling parameters and chemistry of HR coils and annealing parameters of low carbon steels for tinplate application, and critical assessment provides a solution of cost effective tinplate production as per customer's requirements.

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Keywords: cost effective, skin pass rolling, numerical simulation, annealing

1. Introduction

Manufacturing is all about cost effective production. Tinplate manufacturing is the only steel application which is for food packaging, in which quality is the prime concern. Shelf presentation, usage convenience, eco-friendliness, shape ability puts tinplate as customer's best choice. "Amongst all it has the best preservative property and is environment friendly" say researchers [1]. In market, it competes with other packaging media like plastic, glass, paper, aluminum, etc. Decision making point becomes cost of the substrate along with the packaging media Studies indicate that out of the total packaging market of Rupees 35,000 crores only 6 % is tinplate packaging. The tinplate industry in India is under severe threat from two fronts. First, from the manufacturers of tinplate from all over the

world. The second threat for the tinplate manufacturers is the packaging from alternative packaging medium such as tetra packs, polyethylene etc.

Thus it is imperative that domestic tinplate producers should face up to the challenges and build up sustainable business even in the changing environment through optimization of the manufacturing Value Chain of tinplate to enhance the Value proposition of the product .Here we aim to identify and explore the strategic approaches and manufacturing practices adopted by the tinplate manufacturing companies and thereby develop an optimized model which will provide the Indian tinplate industry a Sustainable Competitive Advantage over the alternative packaging medium thereby enhancing the market share of tinplate as packaging medium which is not growing at the rate at which the overall packaging spend is growing in Indian domestic market. The value chain study of the effect of annealing parameters & practices on hardness, optimization of tin coating layer for corrosion resistance, correlation between temper mill extension with chemistry of the coil and mechanical properties for different grades has been done.

2. Objective of Study:
- To establish a correlation between extension in temper mill with the chemistry of HR coil.
- To establish a correlation between extensions in temper mill (skin pass rolling) with the roll force given in both the stands i.e. stand 1 and stand 2 in 4HI mills.
- To establish a correlation between the mechanical properties (UTS and hardness) of the final product with the extension in 4HI mills.
- Finally, correlating together all the above mentioned relations to get a final relation between mechanical properties (customer demand) with the chemistry of incoming HR coils.

3. Overview of the Experiment
- % extension has been taken as a function of roll force in both the mill stands and chemistry of the coil.
  % extension=f(chemistry , roll force in both the stands of 4HI mill)

Thus, % extension along the Y- axis which is a dependent variable   and chemistry of coil and roll force along X-axis which is an independent variable has been plotted.

- Again in another set of plots, mechanical properties (UTS and hardness) as function of extension given in temper mill. UTS , hardness = f(% extension) has been shown

  Thus, mechanical property parameters along Y – axis which is a dependent variable and % extension along X – axis which is now an independent one are shown here

4. Scope of the Application:
- The demands of a customer are coating thickness and desired mechanical properties (UTS and Hardness).
- Since, their demand is known; required % extension to be given to achieve the desired properties is decided.
  % extension to be given can be calculated from the co- relations where the mechanical properties are the Function of % extension.
- Once, the % extension is decided, since chemical composition of coil are known, required roll force to be given in both the stands using the co-relation is derived, where correlation between % extension with the roll force given in both the stands , carbon equivalent and nitrogen content is derived.
  Thus by back tracking the whole process, roll force required to get the required extension is known.

5. Steps involve in the Experiment:

- Collected the data of %extension given in temper mill , coil chemistry , hardness value , and the roll force given in the two stands of temper mill for the grades steel1,steel 2and steel 3.Regarding chemistry of the coil , the considered elements are-carbon , Manganese , Silicon , chromium and Nitrogen . Then converted them in terms of Carbon equivalent (except for nitrogen). the formula used for conversion is-

  Carbon equivalent=(%carbon)+(%silicon+%manganese)/6+(%chromium)/5.

- Then plotted best fitted graphs in MINITAB taking % extension along Y- axis against coil chemistry, and the roll force given in the two stands of temper mill along X-axis. Hence we get 4 best fitted plots for each grade.

  %Extension=f (Nitrogen content, carbon equivalent, avg. roll force stand 1, avg. roll force stand 2)

- Ultimately all these variables are considered that linearly dependent upon each other. Hence, the final equation in the form mentioned below is established-
  $E=aK_1 + bK_2 +cK_3 +dK_4$ where K_1, K_2, K_3, K_4 are constants.
  E= extension at Temper mill,

a, b, c, d are functions of, carbon equivalent, nitrogen content(ppm), average roll force stand 1, average roll force stand 2 .

- Another set of individual plots are made taking Mechanical property parameters(UTS and hardness) along Y−axis and % extension given in temper mill along X− Axis.
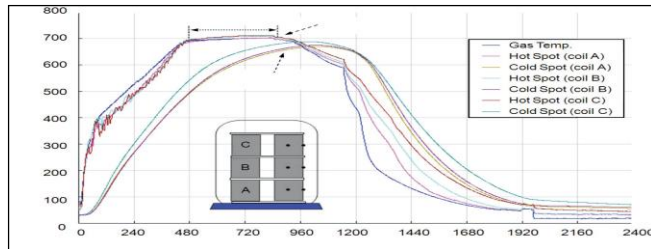
6. Chemistry of HR Coils

Grade	Chemical Composition				
	% C	% Mn	% Si	% Cr	N (ppm)
Steel 1	0.034-0.07	0.20-0.473	0.006-0.034	0.0085-0.004	30-70
Steel 2	0.035-0.075	0.19-.05	0.001-0.058	0.014-0.028	19-64
Steel 3	0.032-0.12	0.19-0.45	0.005-0.018	0.012-0.027	20-58

7. Design of Experiment:

Effects of annealing parameters & practices on hardness:
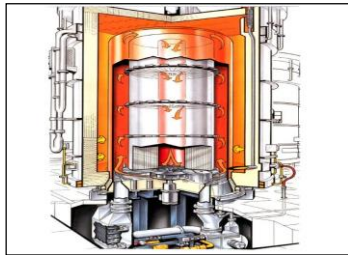
Batch Annealing furnace

Annealing process graph

Six variable[2] matrix is taken that influences recrystallization behavior which include amount of prior deformation, treatment, holding time, initial grain size, composition and amount of recovery prior to the start of recrystallization. Gas temperature, base temperature, temperature between the hot spot and the cold spot, heating time, soaking time are the parameters of annealing. Coil wise data have been collected from over a period of one year. Variation of coil hardness of each temper on the basis the annealing parameters (gas temp, base temp, ΔT, heating time, cooling time, soaking time, stacking position) has been studied and variation of coil hardness of each temper on the basis of percentage reduction and chemical composition (C, Mn, Si, P, Al & N) has also been studied.
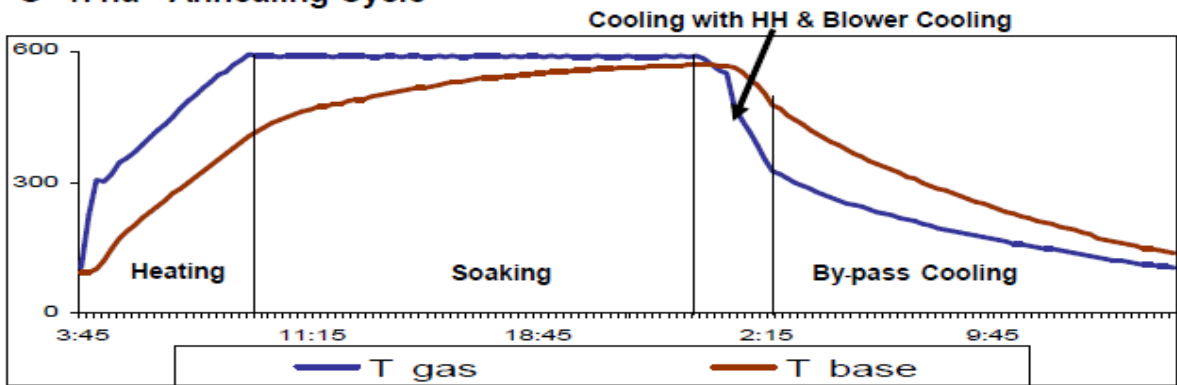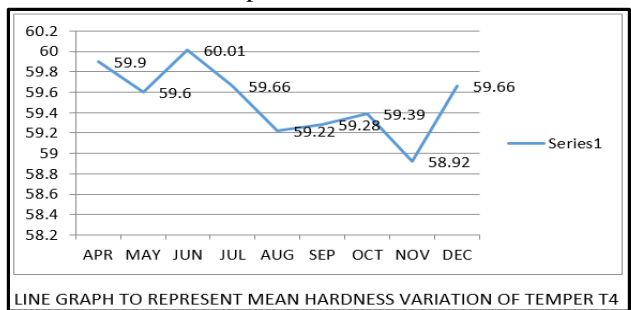

Annealing graph

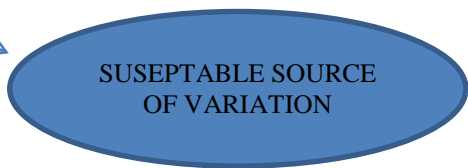Hardness trend of the grades Steel 1 and steel 2 in the above mentioned time span.
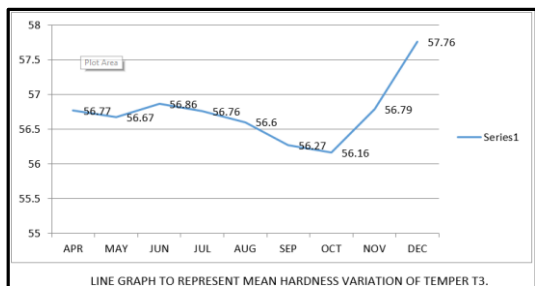

Steel 1

steel 2

SHAININ TECHNIQUE APPLIED (example):

Temper mill hardness	Position	Width	Thick	Tg	Tb	Heat. Up	Soak. Time	Cooling	%C	%Mn	%N	%Extn
55	1	780	0.260	580	567	3:12	11:00	11:35	0.0257	0.002	21	1.45
55	1	780	0.260	580	568	3:12	11:00	11:55	0.0257	0.002	24	1.30
55	1	780	0.270	580	568	3:25	11:00	12:10	0.03	0.0021	24	1.60
55	2	780	0.270	580	571	4:29	11:00	12:15	0.03	0.0021	24	1.72
55	2	780	0.28	580	572	4:32	11:00	12:15	0.03	0.0023	25	1.34
55	2	780	0.300	590	576	5:19	11:00	12:15	0.03	0.0023	26	1.31
55	3	780	0.300	590	576	5:33	11:00	12:15	0.03	0.18	28	1.27
55	3	780	0.300	590	578	5:33	11:00	12:40	0.035	0.18	29	1.68
51	4	780	0.310	590	580	5:34	11:00	12:40	0.035	0.18	29	1.20
51.5	4	780	0.310	590	582	5:35	11:00	12:55	0.035	0.19	30	1.30
51	4	820	0.310	590	582	5:48	11:00	13:00	0.04	0.19	32	1.37
51.5	4	880	0.310	610	599	5:48	12:00	13:05	0.04	0.2	34	172
51.5	4	940	0.310	610	600	5:58	12:15	13:45	0.04	0.2	36	1.79
51	4	960	0.320	610	602	6:05	14:35	14:00	0.04	0.21	40	1.80
51.5	4	960	0.320	610	603	6:20	14:50	14:00	0.04	0.22	40	1.77
51.5	5	980	0.340	610	603	SH	14:50	14:40	0.045	0.22	52	1.80
TOP COUNT	1	6.5	2	2.5	0	0	0	1	0	2	2	2
BOTTOM COUNT	6.5	1	1	3.5	0	0	0	1.5	0	1	1	5
TOTAL COUNT	7.5	7.5	3	6	0	0	0	2.5	0	3	3	7

Grade wise analysis:

SUSEPTABLE SOURCE OF VARIATION
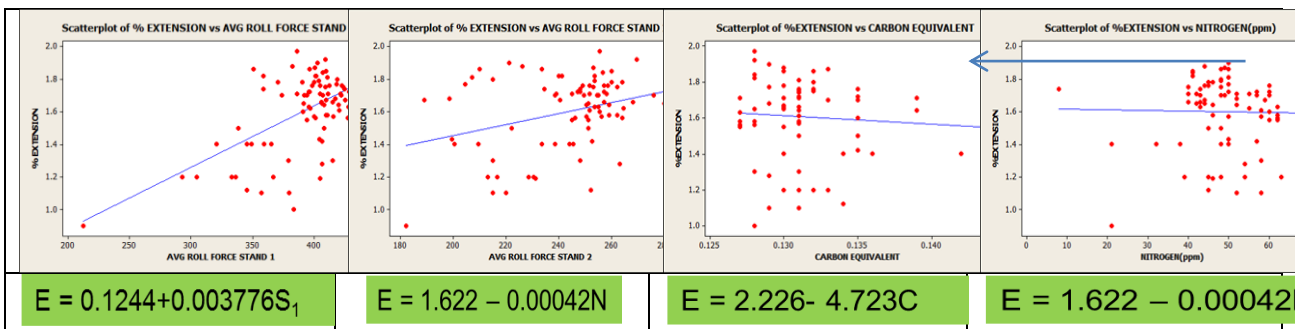
Steel 1

| $E = 0.1244 + 0.003776 S_1$ | $E = 1.622 - 0.00042 N$ | $E = 2.226 - 4.723 C$ | $E = 1.622 - 0.00042$ |

Both the scatter plot shows as the roll force increases in both the stands % extension is also increasing which is there by confirming our literature

Both Nitrogen and carbon equivalent are hardening agents and thus with the increase % extension is reduced, which is confirming to literature.

Putting together all this relations in a single relationship we get:-

$$E = 3.26 + (1.2 \times 10^{-3}) S_1 + 0.25 S_2 - 56C + (6.23 \times 10^{-3}) N$$

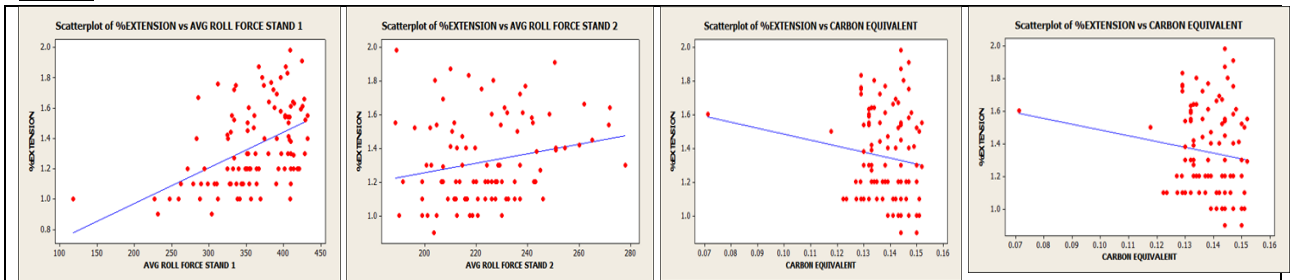Where: E = %Extension given in temper mill

S_1= Average roll force in stand 1

S_2= Average roll force stand 2

C = Carbon equivalent

N = Nitrogen content

Steel 2

Both the scatter plot shows as the roll force increases in both the stands % extension is also increasing which is there by confirming our literature.

Both Nitrogen and carbon equivalent are hardening agents and thus with there increase % extension is reduced, which is confirming to literature.

Correlation of Extension with Chemistry of Coil and Mechanical Properties:

Percentage extension as a function of roll force in both the mill stands and chemistry of the coil is taken and considered as a function of chemistry, roll force in both the stands of 4HI mill. Thus, extension is taken as a dependent variable and chemistry of coil and roll force as an independent variable. In other set, mechanical properties - Ultimate Tensile Strength and hardness are taken as function of extension given in temper mill. Mechanical property is a dependent variable and percentage extension is an independent one here. A grade wise analysis was carried out and an empirical relation is derived.

Annealing Cycle of T3 (**Co-**relation of Hardness with respect to Temperature, Chemistry, Chemical equivalent and Thickness).
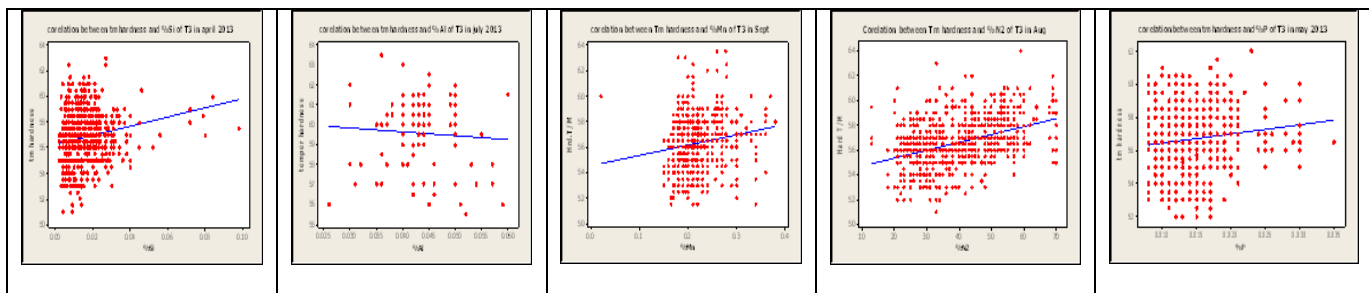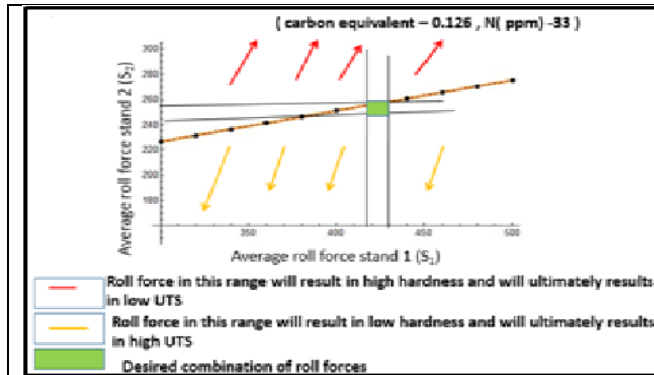
For T3 Temper Co-relation derived:

(0.18-0.23mm) H = 52.76 + 50.96 Ceq | (0.3 mm & above) T/H = 49.08+68.02 Ceq.
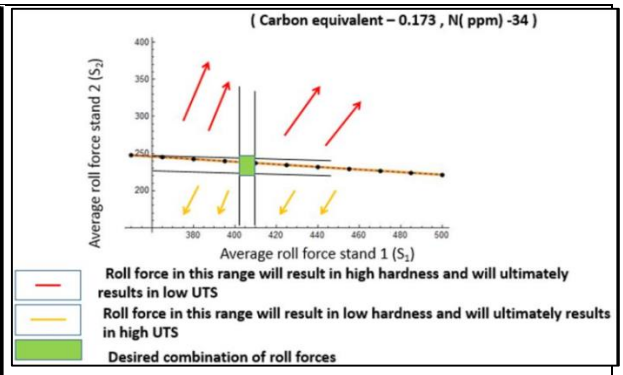
(0.24-0.25mm) H = 51.61 + 52.66 Ceq| H = 42.49+0.025235 Tb

(0.26-0.29mm) H = 53.84 + 29.37 Ceq| H = 55.87+1.71 ST

9. Results:

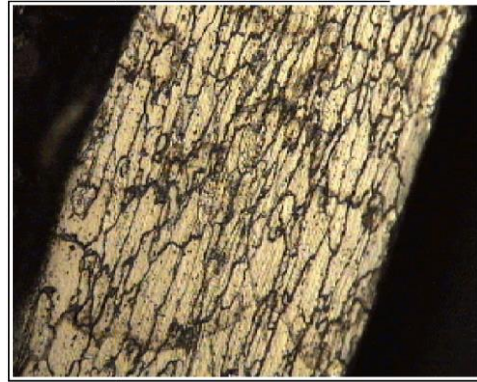| For Grade Steel 1:	For Grade Steel 2:	Where,
$E = 0.5006 + 0.002352S_1$ $E = 0.6943 + 0.002798S_2$ $E = 1.833 − 3.520\ C$ $E = 1.353 − 0.000526N$ $E = 4.68 + (2.18 * 10^{-3})\ S_1 − (8.96 * 10^{-3})\ S_2 − 18.19C + (8.2 * 10^{-3})N$ $U = 413.4 − 0.39E$ $H = 58.18 + 0.2487E$	$E = 0.3581 + 0.00235S$ $E = 0.5238 + 0.002824S_2$ $E = 1.392 − 1.353C$ $E = 1.222 − 0.003069N$ $E = − 0.17 + (6.81 * 10^{-4})\ S1 + (3.89 * 10^{-3})\ S2 + (0.98)\ C − (3.069 * 10^{-5})\ N$ $U = 611.7 − 113.7\ E$ $H = 59.21 + 1.122\ E$	E = % Extension given in temper mill $S1$ = Average roll force in stand 1 $S2$ = Average roll force stand 2 C = Carbon equivalent. N = Nitrogen content. U = Ultimate tensile strength H = Hardness

| Grade Steel 1 | Grade Steel 2 |

Microstructure grains behavior on extension.

Microstructure of less extension sample microstructure of more elongated grains

Less elongated grains   more elongated grains

- If we can maintain the following norms, then the desired extension required for desired mechanical properties can be achieved.

| Average roll force stand 1(N/mm^2)	Average roll force stand 2(N/mm^2)
418-430	245-255
Steel 2: Carbon Equivalent (CE)-0.126%, Nitrogen-33 ppm	

- If we can maintain the following norms, then the desired extension required for desired mechanical properties can be achieved.

Average roll force stand 1(N/mm^2)	Average roll force stand (N/mm^2)
405–415	230–240
Steel 1: Carbon Equivalent (CE)-0.126%, Nitrogen-33 ppm	

- If we can maintain the following norms, then the desired extension required for desired mechanical properties can be achieved.

Average roll force stand 1(N/mm^2)	Average roll force stand 2 (N/mm^2)
402-410	225-240
Steel 3: Carbon equivalent (CE)-0.173%, Nirtrogen-34 ppm	

The higher roll force is performed relatively high extension is achieved and it performs high mechanical properties (Hardness).

Steel 1 grade	Steel 2 Grade	Steel 3 Grade
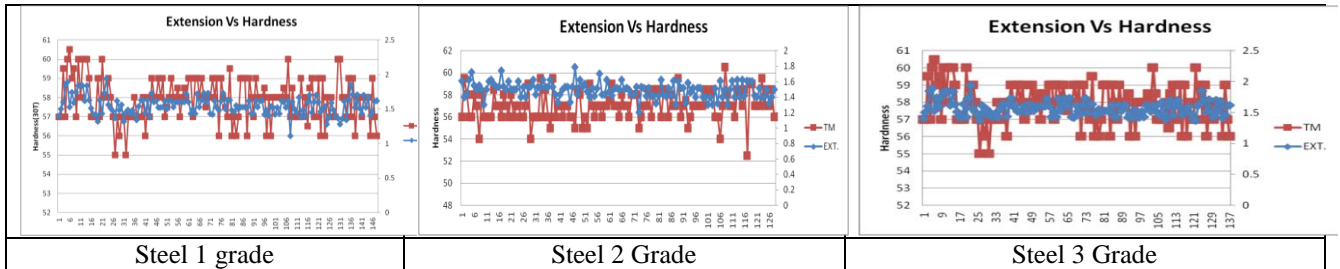
CONCLUSION:

The demands of a customer are coating thickness and desired mechanical properties can be attained. Depending on their demands, the percentage extension to be given to achieve the desired properties is established. Percentage extension to be given can be calculated from the co- relations where the mechanical properties are the function of percentage extension. Once we have decided the percentage extension, since chemical composition of coil are known to us we can decide the roll force to be given in both the stands using the co-relation where we have co - related percentage extension with the roll force given in both the stands, carbon equivalent and nitrogen content. Thus by back tracking the whole process we can reach a desired conclusion , where we can decide what amount of roll force is required to get the required extension.

References:

1. Batch Annealing Model for Cold Rolled Coils and Its Application,**CHUN-JEN FANG and LI-WEN WU**
2. MULTI-VARIABLE RELATIONSHIPS IN A BATCH ANNEALING PROCESS David J Scott∗, Ken Russell† and Judi Scheffer.